A

DISSERTATION REPORT

ON

Designing And Analysis of AND, OR, XOR, NOT Logic Gates Based on Coupled Metal Gap Waveguides

submitted in partial fulfillment for the award of degree of

MASTER OF TECHNOLOGY IN ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by:

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JAIPUR (JUNE 2019)

CERTIFICATE

This is to certify that the dissertation report entitled **"Designing And Analysis of AND, OR, XOR, NOT Logic Gates Based on Coupled Metal GapWaveguides"** submitted by **Pankaj Binda (2017PEC5256)**, in the partial fulfillment of the Degree Master of Technology in **Electronics and Communication** of Malaviya National Institute of Technology, is the work completed by her under our supervision, and approved for submission during academic session 2018-2019.

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DECLARATION

I, **Pankaj Binda**, declare that this Dissertation titled as **"Designing And Analysis of AND, OR, XOR, NOT Logic Gates Based on Coupled Metal GapWaveguides"** and the work presentedin it is my own and that, to the best of my knowledge and belief.

I confirm that major portion of the report except the refereed works, contains no material previously published nor present a material which to be substantial extent has been accepted or the award of any other degree by university or other institute of higher learning. Wherever I used data (Theories, results) from other sources, credit has been made to that source by citing them (to the best of my knowledge). Due care has been taken in writing this thesis, errors and omissions are regretted.

Date: **PANKAJ BINDA**

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List of Abbreviation

• FDTD	Finite-Difference Time-Domain
• SPP	Surface Plasmon Polaritons
• MDM	Metal Dielectric Metal
• TE	Transverse Electric
• TM	Transverse Magnetic
• 1D	One Dimension
• 2D	Two Dimension
• 3D	Three Dimension
• WDM	Wavelength Demultiplexing

Abstract

Design the Boolean logic gates in this thesis. Boolean logic gates device is based on the coupled metal waveguides. Theoretical analysis are done for the boolean logic gate on the based of four maxwell equation. Two circuit are design for the four logic gate such that AND, OR, XOR, NOT gate. The one device can perform individually two different kinds of basic functions are AND and OR operations. Other device can perform individually two different kinds of basic functions are XOR and NOT operations. The size of device is very small even in the micrometer. LASER is used as a source which is wavelength 1550nm. Silver is used as a metal and air is present between the gap of two metal. There are three input port as well as three output port. Input port W1 and output port O1 are used in AND gate. Input port W2 and output port O2 are used in OR gate. Input port W1 and output port O3 are used in XOR gate. Input port W1 and W2 and output port O3 are used in NOT gate. Calculate the extinction ratio of all four AND, OR, XOR, NOT gate operation. Simulation of all input combination of all logic gate is shown in this thesis. Calculate the output intensity at the output port using the observation graph. Vertical observation tool is used for calculate the output intensity. All output intensity is measure in normalized. All simulation and calculate of the all cases of all logic gate are done on the FDTD.

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Chapter *1*

Introduction

Light control at nanoscale metal-dielectric-metal design is requires the structure which follow the property of diffraction limit of light, that is not provide by conventional photonic elements. When electromagnet wave passing through the metal gap waveguide, free electron oscillation in the metal and wave propagate along the metal dielectric surface. This wave is called the SPP wave. This wave follow the maxwell equation. The optical circuit which follow the SPP wave is a provide the nanoscale or ultrasmall optical circuits. The interact of surface plasmons with light in the metallic property structures which is most used recently for the design of ultrasmall optical(photonic) device by nanofabrication technology at the microscopic scale into real world. Many experimental and theoretical works are occur on the photonic device using SPP waves. On the basis of the SPP wave property, many nanoscale photonic device are made such as reflectors, waveguides, beam splitter and filters. LL the optical circuit in nanometer which are very small and its used in the fabrication of the device. Many type of the waveguide are used for optical device such that metal films, metal wedges[1]. More interesting topic is that the combination of the conventional optical devices with SPP wave provides the integration and nanoscale optical deviceus. Surface plasmon polaritons (SPPs) wave are visible or infrared frequency electromagnetic waves which is travel along a metal–dielectric interface or air-metal interface. It is also explains that the wave involves both charges movement in the metal which is electromagnetic waves and surface plasmon in the dielectric or air which is polariton. Surface plasmon polaritons based devices have significant attention over the last decade with usefull applications like negative refraction, optical cloaking,and meta-surfaces. They have also capable to highly efficient and usefull electro-optical devices bridging the gap between optical (micron) and the electronics (nano) scale devices[2]. Many devices and their applications are multi-layer metal insulator structures, where the interaction of surface plasmons at various interfaces provide these surprising properties.

1.1 Electromagnetic Surface Waves, Surface Plasmons,and Plasmon Polaritons

The eigenmodes of collective oscillations of the quasi-free electrons in metals are called plasmons. An electrons have a charge, these oscillations is interact with an electromagnetic field. Then a theoretical represent the interplay of fields and charge. When waves trapped on metal-dielectric interfaces and coupled to propagating free electron oscillations in the metals is called surface plasmon polaritons (SPPs). SPP waves propagate in the optical circuit[3] and reduce the propagation losses. Size of the optical circuit in nanometer then it is used for the integrated circuit. Solutions of Maxwell's equations provide surface plasmon polaritons wave in which the effects speed of light is consider. Surface plasmons is phenomena in which surface plasmon polaritons wave are propagate at the interface of metal dielectric metal. When wave is propagate at the interface of metal dielectric metal due to Surface plasmon polaritons then speed of light is infinitely. The Laplace's equation provide the solution of the spp wave propagate along a planar dielectric–metal interface for a scalar potential. Many number of geometries commonly used in the study of SPP resonant modes, and these are illustrated in Fig. 1.1.[4]. One common structure is metallic resonant nanoparticles and spheroids structure which have been studied deeply in recently year and most used for their ability to used to nonlinear wave mixing. And today, it is advances in nanoscale fabrication and characterization techniques. It become increasingly possible to study "engineered" structures designed to have specific resonant properties. In this thesis, the focus is on surface plasmons polaritons (SPPs), the electromagnetic eigenmodes at planar metal-dielectric interfaces. SPPs in the optical device have been deeply studied for many years. Actually , these surface plasmon modes were studied by Zenneck (1907) in 20th century and Sommerfeld in connection with wireless telegraphy and so it is called Zenneck modes. In intially study focused on frequencies much smaller than visible

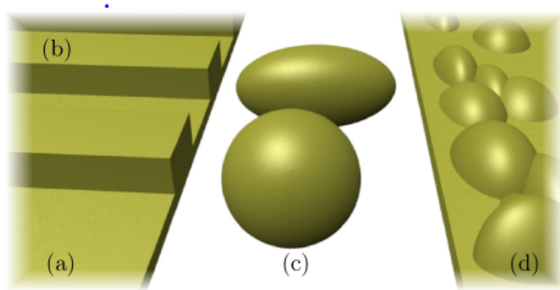


Figure 1.1: Different type of plasmon resonance nanostructure structure. (a) planar metal surface (b) currogated surface (c) spherical and spheroidal nanoparticles (d) randomly rough metal surface

light frequency. Study of the spp wave for many years ago. It optical properties of metals is explain by the Drude-Sommerfeld model in which calcutale the relative permeability of silver at the different frequency. SPP waves follow the maxwell equation and with the help of laplace equation is provide the solution of maxwell equation. Relative permeability of silver[5] is depend upon the plasma frequency, wavelength and omega frequency. There recent work in which among other things, has explored SPPs potential for made various integrated optical devices.

1.2 The Surface-Plasmon Condition.

We have two semi-infinite nonmagnetic media having frequency-dependent dielectric functions ε_1 and ε_2 separated by a planar interface at z = 0 is shown in figure 1.2.[6]. It follow the Maxwell's equations

$$\frac{\partial \mathcal{D}_\rangle}{\partial t} = \nabla \times \mathcal{H}_\rangle \tag{1.1}$$

$$\frac{\partial \mathcal{B}_\rangle}{\partial t} = -\nabla \times \mathcal{E}_\rangle \tag{1.2}$$

$$\nabla \cdot \mathcal{B}_\rangle = 0, \tag{1.3}$$

$$\nabla \cdot \mathcal{D}_{\rangle} \quad = \quad 0. \tag{1.4}$$

where i = 1 at z < 0 and i = 2 at z > 0.

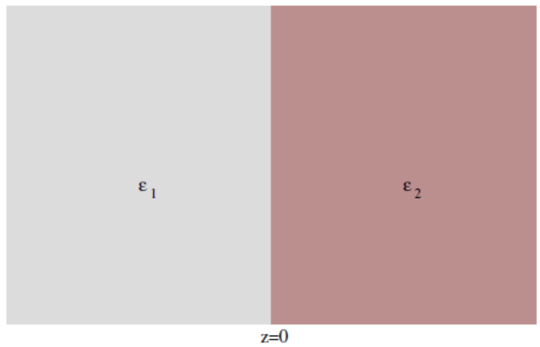


Figure 1.2: Two semi-infinite media with dielectric functions ε_1 and ε_2 separated by a planar interface at z = 0.

Using of equations (1.1)–(1.4)[6] are defined into both s-polarized and p-polarized electromagnetic modes, E the electric field parallel to the interface and the magnetic field parallel to the interface. Electric field component normal to the surface, then wave are formed and propagate along the metal dielectric interface for an ideal surface[3]. Magnetic field follow the maxwell equation and electric field follow the maxwell equation. Electric, magnetic field,omega are used for the calculation of the derivation of the surface plasmon condition. Component of magnetic field parallel to the metal dielectric interface and propagate along the surface and when component of the electric field is parallel to the metal dielectric interface, then s-polarized surface oscillations do not exist. Both fields tailing off into the positive direction (z > 0) and negative direction (z < 0).

$$\kappa_1 i H_{1y} = \tfrac{\omega}{c}\varepsilon_1 \, \mathrm{E}_{1x} \tag{1.5}$$

$$\kappa_2 i H_{2y} = -\tfrac{\omega}{c}\varepsilon_2 \, \mathrm{E}_{2x} \tag{1.6}$$

$$\kappa_i = \sqrt{q_i^2 - \varepsilon_i \frac{\omega^2}{c^2}} \tag{1.7}$$

Component of the magnetic field parallel to the metal dielectric surface and component electric field parallel to the metal dielectric surface should be continous for apply the boundary conditions. Calculation of the whole field is using the maxwell equation. Magnetic and electric field are perpendicular to each other. Solving equations (1.5) and (1.6), writes the equations of system.

$$\frac{\varepsilon_1}{\kappa_1} H_{1y} + \frac{\varepsilon_2}{\kappa_2} H_{2y} = 0 \tag{1.8}$$

$$H_{1y} - H_{2y} = 0 \tag{1.9}$$

if the determinant is zero,it is provide solution

$$\frac{\varepsilon_1}{\kappa_1} + \frac{\varepsilon_2}{\kappa_2} = 0 \tag{1.10}$$

This is called surface-plasmon condition.

1.3 Optical Properties of Metals

A simple model for the study of free electrons in metals was developed by Drude (1900) based on the kinetic gas theory. Relaxation time of free and independent free are same in this model. Assumption of the property of many metal is correct in the Drude-Sommerfeld model. At optical frequencieselectromagnent frequency it is not used for optical device due to the presence of interband transitions[7]. The basic properties of metals of this theory is a gas of independent electrons. These electrons move freely between collisions with undefined independent collision centers such that (phonons, defects, other electrons, lattice ions etc). Complete loss of directional information due to collision. The electrons are accelerated between collisions to provide in a drift motion when it is present in external field. It is provide to contribute the electrons near the fermi level. Drude model are usefull for calculating the relative permibilitty of any real metal. Optical properties of many real metal are defined by the frequency dependent ε dielectric function using this Drude model.[8] The resulting equation for the dielectric function is:

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p}{\omega^2 + i\omega\gamma} \tag{1.11}$$

In this model where ε_∞ is the interband-transition contribution to the permittivity, ω_p the bulk plasma frequency, and γ the electron collision frequency. ε_∞ = 3.7, ω_p =9.1eV and γ=0.018eV[8] . The collective oscillations of the quasi-free electrons oscillate resonantly when it is placed at the plasma frequency and these eigenmodes are consider in the plasmons. This model is very usefull for the optical device. Without this model we cannot calculate the relative permittivity of the silver at the different frequency. ε_∞ , ω_p , γ , ε_∞ is depend upon the wavelength. All parameter are varying according to the material and wavelength. Electromagnetic boundary conditions cause to different conditions of plasmons when the infinite metal is terminated by a surface. It is initial and most usefull condition for the surface plasmon. Free electron present in the metal which are oscillation within the metal. All optical device is very usefull for the nanometer size device due to less propagation losses. It is very usefull for the integrated circuit. This free electron generate the spp wave which propagate along the metal dielectric surface.

1.4 Surface Plasmon Polaritons at the Metal-Dielectric Interface

The electric field intensity in the metal and the electric field intensity in the dielectric medium falls off exponentially in the direction normal to the interface of metal dielectric surface. The boundary between the dielectric medium and the metal is present in the x-y

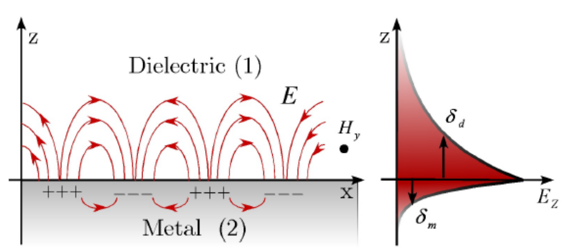


Figure 1.3: SPP modes at a smooth metal-dielectric interface. There fields are maximal at the interface as well as decay exponentially into both media.

plane as shown in Figure 1.3.[4] Consider that SPP propagation in the positive x direction with the fields expose into the positive z directions and negative z directions.

The electric and magnetic field intensity provide in the metal and there charge also provide in the metal. When it is propagates as a longitudinal wave along the surface in the plane of the interface. That is SPPs propagate along the metal dielectric interface and Electromagnetic fields is highly place at the metal dielctric interface area as well as energy is highly place at the metal dielctric interface area and charges is highly place at the metal dielctric interface area.[9]. First region is dielectric which is air in this thesis and second region is metal which is silver in this thesis. Free electron oscillation in the metal and generate the SPP wave. Size of the transistor is ultrasmall due to size of the optical device in nanometer parameter. Magnetic field decrease exponentially in the metal medium and dielectric medium. Electric field decrease exponentially in the metal medium and dielectric medium. Property of SPP wave is depend upon the property of the metal and property of the dielectric.

1.5 Surface Polariton Scattering

Surface polariton scattering is occur at the interface of metal dielectric metal by surface features. Scattering of SPP wave along the interface. The SPP wave interaction with a metal surface is defined by three processes, which is scattering of SPP into SPP reflection, propagation of SPP through the interface the metal dielectric metal region in the same direction, scattering of SPP wave into output light which shown in figure 1.4.[10]

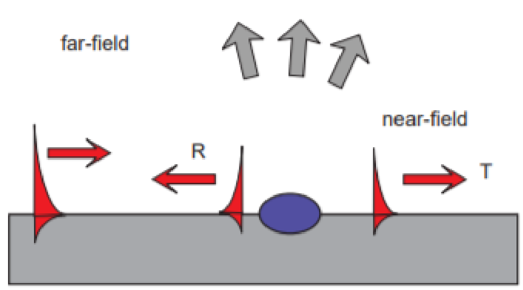


Figure 1.4: SPP scattering processes on a topographical surface

Study the latter process is possible only using the conventional far-field measurements in last past years. SPS process always occur in the metal gap waveguide. Update the surface structure in multiple way and behavior. The scattering processes is depend on the size, the dielectric constant[11] and geometrical shape of the metal dielectric metal surface. It plays a important rule to calculate optical properties of metal film and nanostructured metal films. Some time scattering cause to losses, when reflection scattering is dominant than the propagation of spp wave and light in the form of output at output port. But it is not occur. The propagation of spp wave and light in the form of output at output port is dominant process than the reflection scattering. Then spp wave propagate at the interface metal dielectric surface. SPP wave are generate in the scattering process. Three process are done in the scattering process. All three process in the optical device are done at the same time. The surface polariton scattering which is very complicate process in almost all case requires tedious numerical modeling. To better knowledge how to SPP scattering process are occur. The gradient of the metal dielectric metal structure variations should be consider. Scattering process in which light propagate at interface the metal dielectric. There three process very usefull for the scattering in which reflection light, light propagate at interface the metal dielectric, light passing through the output at output port. Calculation of the output intensity is measure by the observation tools. Scattering process always done in the presence of input light. This process in the region of the metal gap waveguide then it is measure by the vertical observation tools. Common process that slow varying in metal dielectric metal structure. Additional specification of SPP interaction with metal surface at a interact of metal dielectric metal structure.

1.6 Surface Plasmon Dispersion

Surface plasmon modes are most easily analyzed and Investigation in a planar two-dimensional device structure where the metals on either side of the dielectric are assumed to be the same. The two metal dielectric interfaces lead to the break of the degenerate modes at that interfaces. Metallic stripe waveguides have found wide applicability in a plasmon optical devices. Multilayer metals dielectric structures to wavelength scale dimensions device one can construct base on plasmon resonators. It is structure suitable for optoelectronic applications. The round trip of phase for SPPs must be an integer multiple of 2pie and follow from the resonance condition. Dispersion relationship with both modes is very usefull for the optical device. There are two modes such that symmetric and anti symmetric. Symmetric modes in which magnetic field profile is symmetric about the thickness of the metal gap waveguide ”d” and anti symmetric modes in which magnetic field profile is anti symmetric about the thickness of the metal gap waveguide ”d”. The resonant width is depends on the order of the resonance in the case of the MDM cavity. A metal dielectric metal structure and a plot of the plasmon dispersion relation[12] is shown in above figure. For very small metal thickness, the modes in the structure break like modes in the metal dielectric metal structure. Symmetric modes in the metal structure guide most of their energy passing through the dielectric .it is cause to long propagation length.

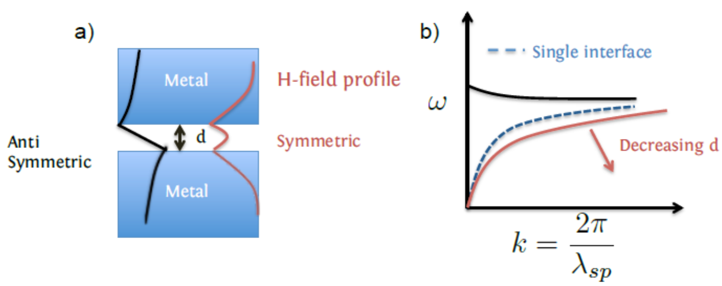


Figure 1.5: (a) MDM structure and the magnetic field profile for the symmetric and anti-symmetric modes. (b) Dispersion relationship for the two modes.

Modes have symmetric and anti-symmetric field profile in symmetry structure is shown in Figure (1.5 a)[13]. Resulting dispersion relationship for there modes in symmetry structure is shown in Figure (1.5b)[13]. The symmetric mode dispersion shifts to the right due to decrease thickness of dielectric layer ’d’ lead to giving the group velocity and mode lower wavelength. When increased losses as well as a lower propagation length due to a larger fraction of the mode energy is stored in the metal. This high index mode is strongly restricted with large electric fields in the dielectric structure. When increase the value of k then increase the group velocity in the single interface but decrease the value of the d then when increase the value of k then increase the group velocity but maximum value of the group velocity in single interface is greater than the value of the group velocity in the decrease the value of d. It is also high optical density of states which is makes it an attractive mode to target for improve light matter interaction. It is Shifts towards the light line when anti-symmetric mode dispersion on the other hand and has a larger fraction of its energy passing through the dielectric. The other structure to the MDM geometry is the DMD geometry, a thin metallic plate surrounded by dielectric on either side. It is provide as guiding light below the diffraction limit, nano-scale optical waveguides.

1.7 Materials Used

Plasmonic materials are metals for near-infrared and visible light due to their property of free electrons. Ohmic losses is not commonly used for optical device but it can be minimize in the metal. Recently, fabrication of new material which is used for optical device. The SPP propagation lengths(micrometer) and quality factors(millimeter) for four common plasmonic metals; Ag, Al, Au and Cu.

Chapter *2*

Literature Survey

Many researcher are publised there paper on the based of metal-dielectric-metal structure. They are investigation in the metal-dielectric-metal structure to form all optical logic gate. They are experimently prove the propagation of Surface plasmon polaritons wave passing through the metal gap waveguide. Different type of solution are provide to reduce propagation losses in each paper. Most researcher are there work continous on this topic. They are reduce the propagation losses by many technology. SIX paper are used for this thesis. They are provide the new technology to reduce the propagation losses in there paper. Investigation in the metal-dielectric-metal structure for more than 20 years. They are provide new structure of logic gate to reduce size of transistor. We are also design all the logic gate with the plasmonic gap waveguide coupled structure in many paper to reduce the propagation losses.

(1) Jing Wen, Jiannong Chen, Kang Wang, Bo Dai, Yuanshen Huang, Dawei Zhang

In this paper, we design the broadband plasmonic logic source which is applied to the two parallel plasmonic gap waveguides coupled with dual square ring resonators in the vertical or horizontal manner. The white source is applied at the input port of plasmonic gap waveguide with the different wavelength filter. The coupling length of the plasmonic gap waveguide is 3000nm at thickness plasmonic of the 30nm. The coupling length of the plasmonic gap waveguide is 2612nm at thickness of the 20nm. Both the coupling length of the plasmonic gap waveguide is measure at the 1550nm. The thickness of the dielectric is 60nm. This concept is used in the optical computation unit. Compose the three input logic gate such that AND and OR gate with the white source in this paper.[14]

(2) X. zhou1, Y. fu2, K. li1, S.wang1, Z. cai

In this paper, nanophotonic U-shaped circuit on the based of coupled metal gap waveguide. U-shaped circuit in which air as a dielectric and silver as a metal. Surface plasmon polariton waves are generate at the interface of the metal and dielectric. This waves move along the interface of the metal and dielectric. Input signal applied at the three input port and calculate the output intensity at the three output port. LASER signal used as the source which applied at the input port. Logic "1" and logic "0" are defined after the decision the value of threshold. The phase difference between at the two output port is varying in change of thickness of U-shaped corner. This circuit is used in the the future computation units.[15]

(3) Zhanghua Han, Erik Forsberg, Sailing He

In this paper, Relative permittivity of silver is obtained by the drude model. Equation of drude model is 1.11. Design Bragg gratings by a periodic variation of the width of the insulator in a metal-insulator-metal waveguide. Consider a air as a dielectric and silver as a metal. Surface plasmon polariton waves are generate at the interface of the metal and dielectric. Simulation of all input signal are done by the finite-difference time-domain in this paper. Change in the real part of the effective refractive index of an metal-insulator-metal waveguide according to change in width of the air(insulator) at 1550 nm.[8]

(4) William L. Barnes, Alain Dereux and Thomas W. Ebbesen

Explain the surface plasmon polariton waves are generate at the interface of the metal and dielectric. How are this waves move along the interface of the metal and dielectric. All this phenomena are explains in this paper. The electric field intensity in the metal as well as the dielectric medium falls off exponentially in the direction normal to the surface. When surface plasmon polariton waves is propagates as a longitudinal wave along the surface in the plane of the interface. That is SPPs propagate along the interface with electromagnetic fields, energy and charges is highly localized within the interface area. The two metal dielectric interfaces lead to the break of the degenerate modes at that interfaces. Modes have symmetric and anti-symmetric field profile in symmetry structure.

Resulting dispersion relationship for there modes in symmetry structure. The symmetric mode dispersion shifts to the right due to decrease thickness of dielectric layer ”d” lead to giving the group velocity and mode lower wavelength.[16]

(5) Zhiwen Kang and Guo Ping Wang

Coupled wave theory are depend on the coupling length of guided in the metal-dielectric-metal structure. Surface plasmon polaritons wave generate at the different wavelengths with high extinction ratio. Simulation of all input signal are done by the FDTD in this paper. For silver metal two modes are used, that is Symmetry and antisymmetry SPP modes in the metal gap waveguides. Energy of SPP wave are transfer from one waveguide to another waveguide. The coupling length of SPPs in two adjacent waveguides is depend on the π , m and C where C is also depend on the Symmetry and antisymmetry SPP modes and m varying 0 to infinity.[17]

(6) Bing Wang and Guo Ping Wang

In this thesis show that control the SPP wave in the metal gap waveguide as well as many logic gate are propose in the metal gap waveguide. SPP wave passing through the two metal gap waveguide in which first splitting the metal gap waveguide and second is recombining the metal gap waveguide. Coupling the both type of metal gap waveguide are used in the formed of Mach–Zehnder interferometers which is nanoscale. This metal gap waveguide is find out nonlinear and linear dynamic behavior of EM waves. Provide efficient sensing in this paper for metal gap waveguide structure.[18]

(7) Kazuo Tanakaa and Masahiro Tanaka

In this thesis, SPP wave propagate between the two parallel metallic plate. Phase velocity of SPP wave is control by the gap of the metal gap waveguide. Phase velocity of SPP wave is less in the narrow gap of metal waveguide than in the wide gap of the metal waveguide. Phase velocity of SPP wave is depend on the size of the metal gap waveguide. Characteristics of SPP wave is depend on the material, wavelength. Simulation of the bending, branching and straight structure of the metal gap waveguide in this paper.[19]

Chapter *3*

Finite-Difference Time-Domain Method(Simulation Tool)

The output of simulation is the Electric and magnetic fields in time.[20] The simulation is ongoing the Data processing may be occur. FDTD technique computes electromagnetic fields in each cell, then scattered or radiated far fields can be obtained. Initially, Computational domain must be find out. It is also used for Electric and magnetic fields directly. FDTD used the tool for the simulation of the optical circuit which design on the FDTD tool. Hence most of modeling applications are interested in the Electric and magnetic fields. It is follow the four maxwell equation. Finite-difference time-domain simulation software is usefull of simulating of magnetic and electric. The electric or magnetic field of perfectly conducting materials is zero. Permeabilities or Permittivities of this material is negative at some frequencies. nonlinear materials.

3.1 FDTD Models and Methods

FDTD are simulated on based of Maxwell's differential equations and they are represented in equation 3.1 to equation 3.4.

$$\frac{\partial \mathcal{D}_\rangle}{\partial t} = \nabla \times \mathcal{H}_\rangle \tag{3.1}$$

$$\frac{\partial \mathcal{B}_\rangle}{\partial t} = -\nabla \times \mathcal{E}_\rangle \tag{3.2}$$

$$\nabla \cdot \mathcal{B}_\rangle = 0, \tag{3.3}$$

$$\nabla \cdot \mathcal{D}_\rangle = 0. \tag{3.4}$$

When Maxwell's differential equations in which the change in the Electric-field in time (the time derivative) is dependent on the change in the magnetic-field across space. This results in the basic of Finite-difference time-domain time-stepping relation that the latest value of the Electric-field in time is dependent on the stored value of the Electric-field at any point in space and the numerical curl of the local distribution of the magnetic-field in space. The magnetic-field is a time-stepped, the latest value of the magnetic-field in time is dependent on the stored value of the magnetic-field at any point in space. Electric field in the x direction and electric field in the y direction are perpendicular to each other and both are perpendicular to the magnetic field in z direction in the TE mode. Magnetic field in the x direction and magnetic field in the y direction are perpendicular to each other and both are perpendicular to the electric field in z direction in the TM mode. Both TM and TE mode are represent in the 2D structure. Both TM and TE mode are represent in the 3D structure and connect to each other at the perpendicular. It is yee grid 3D structure. There are three 1-D, 2-D, and 3-D Finite-difference time-domain techniques is shown in figure (3.1).

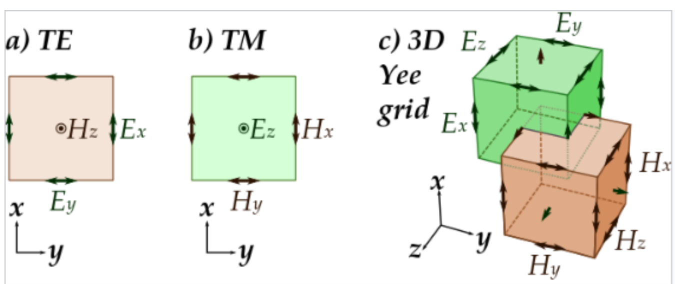


Figure 3.1: Standard Cartesian Yee cell (a) TE mode (b) TM mode (c) Multiplicity of Yee cells in 3D

Yee proposed a leapfrog process for marching in time domain in which the magnetic field and Electric field updates are reel. During each time-step electric field updates are conducted midway between successive magnetic field updates. Both TM and TE mode in 2D are used in the simulation of the optical ciruit. The 3D structure of the both TM and TE both are used in the critical optical circuit. Sometime three model is shown in figure 3.1 is used in the optical circuit for simulation on the FDTD. Many thousands of time-steps is used for simulation of program in the FDTD using maxwell equation.

3.2 Why Use FDTD Simulation Software

In the frequency-domain, there are many electromagnetic simulation techniques. FDTD solves Maxwell's equations in the time domain. It is means that the calculation of the electromagnetic field component values progresses at discrete steps in time. Advantage of the time domain approach in which broadband output from a single simulation of the program. The excellent scaling performance of the method is used in FDTD approach. FDTD is very fast and smart tool for simulation of the optical circuit in the nanometer scale. FDTD takes the less time for simulation of the optical circuit. Update version always present in the internet. FDTD is become simple and take less time for simulation day by day. All the parameter are change in the FDTD at any time of instant. FDTD is simple tool. It is big advantage of the FDTD. Change the wavelength of the light, change of half width of the input signal, change in the position of the input signal, change in the power of input signal, change in the amplitude of the input signal at any time in the FDTD. Change the position of the observation vertical line, Change the position of the observation horizontal line, Change the position of the observation point at the any time in the FDTD. As the number of unknowns parameter increases, the FDTD approach quickly catch in efficiency.

3.3 Input Source and Observation Source

LASER is used as a source in the FDTD. It is emits the light which is coherent. LASER is different from other source because it is coherent in nature. It is full form of LASER is light amplification by stimulated emission of radiation. Three wavelength windows are used for optical application which is 850nm, 1310nm, 1550nm. Mostly 1550nm wavelength is used for the optical application as well as used in the FDTD. A laser is also provide optical feedback. Power of the LASER is change at any time in the FDTD as well as amplitude of LASER is change at any time in FDTD. But sometime light is passing through the cavity lead to losses the output. Observation objects is work in time domain for the 32-Bit FDTD simulation as well as spectrum analysis can be performed in analyzer. No any input source is used in FDTD expect the LASER. Observation Points is work in time domain for 64-Bit FDTD simulation in each single point, during the simulations observation Area will perform the spectral analysis. Due to huge volume no time domain response data is stored for Observation Areas. Many input signal are apply at any place in the FDTD. Observation Points or Observation Areas must be present for 64bit FDTD simulations.

3.3.1 Observation Point

Observes point work in the frequency domain and time domain response. The transmission function can be find out from the Observation Point analysis. Radius of observation Point is change according to the user. It is provide the power(normalized) spectrum versus wavelength(micrometer).

3.3.2 Observation Line

It is two type of line which is vertical and horizontal. Both the Observation Line is used according to user. It is provide the power(normalized) spectrum versus wavelength(micrometer). Position of vertical and horizontal line is defined by the user.

Chapter *4*

Design of AND, OR, XOR, NOT Logic Gate Based on the Coupled Metal Gap Waveguide

We design the multifunctional logic gates based on coupled metal gap waveguide. All gates are design with help of silver as a metal and air as a dielectric on the FDTD. FDTD work in the time domain. It is follow the maxwell equation. All logic gate can be formed in the nanoscale or ultrasmall optical circuit. Top view of refractive index of silver and air. Refractive index of metal is 0.12 which is shown in blue colour and refractive index of air is one which is shown in red colour at 1550nm. Refractive index of both silver and air are shown in figure 4.1.

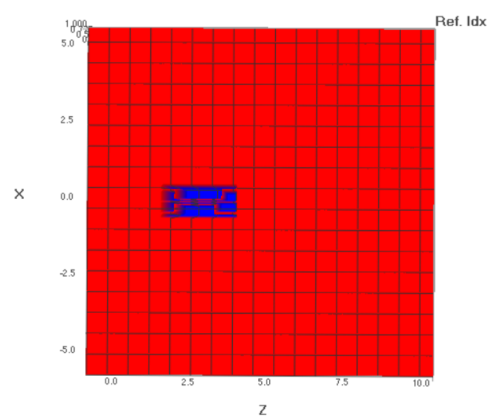


Figure 4.1: Top view of refractive index

The size of logic gate is very small due to coupling length of coupled metal gap waveguide is very small. Aim of this paper is minimum coupling length. AND,OR,XOR,NOT logic gate are design in this paper. It is design based upon the metal-dielectric-metal model. The refractive index is varying according to the change in the wavelength. We are select 1550nm wavelength from the three 810nm, 1310nm, 1550nm window wavelength. The refractive index of silver at the three window wavelength is shown in the table 4.1.

Table 4.1: Refractive Index of Silver

Wavelength(nanometer)	**Refractive index**
810)	0.04000
1310	0.11124
1550	0.1444

The air which relative permittivity is one used as dielectric materials and silver whose frequenc dependent complex relative permittivity is characterized by the Drude model in equation 4.1 used as a metal. Relative permittivity of silver is calculate from equation 4.1 for this thesis.

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p}{\omega^2 + i\omega\gamma} \tag{4.1}$$

In this model where ε_∞ is the interband-transition contribution to the permittivity, ω_p the bulk plasma frequency, and γ the electron collision frequency. ε_∞ = 3.7, ω_p =9.1eV and γ=0.018eV .

We used the LASER as a source rather than LED. Because the LASER is more advantage over LED. Wavelength of LASER is 1550nm. LASER work on based of the stimulated emission of electromagnetic radiation and it is mostly used in the FDTD. The light emits from the LASER is passing through the metal gap waveguide without the losses. That is reason LASER is mostly used in the FDTD as a source. LASER is coherent source which emits the light in particular direction. When also apply the 810nm wavelength, 1310nm wavelength on the FDTD but it lead to attenuation loss and scattering loss. Two type of source are used in FDTD in which vertical and horizontal LASER. In this work, Horizontal LASER is applied at the input port which emits the light in horizontal direction through the metal gap waveguide. Change the intensity of LASER according to the user.

LED source cannot used as source in FDTD. There are characteristic of LASER source is shown below the table 4.2. Also there are three observation port (O1,O2,O3). Many type of observation such that vertical line, horizontal line, point. In this simulation we are used the plane observation vertical line.

Table 4.2: LASER at 1550nm

Type	Gaussian modulated Continous Wave
Input Power(W/m)	1
Half Width(micrometer)	0.015
Central position (micrometer)	0.34, 0, -0.34

4.1 Layout Model

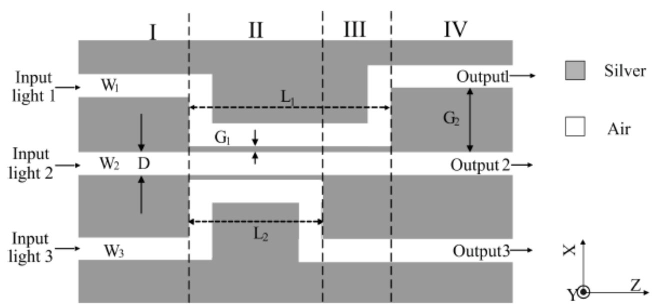


Figure 4.2: All Optical Integrated Logic Device.

Firstly we design the layout model shown in figure 4.2.[22] Coupling length of metal gap waveguide are present in the (II and III) regions. Other two (I and IV) regions are used for avoid loss. The length of the regions (I and IV) is varying according to the thickness of the input port and coupling length. Increase the thickness of the input port then increase the thickness of the metal in the region (I and IV) . There are three input port(W1,W2,W3) in which LASER light is applied which wavelength is 1550nm. The light is propagate in the metal gap waveguide through all fours regions. Firstly light passing through the region (I) then passing through region (II). In region (II and III) light is coupled each other and then passing through region(IV). Light is used for excitation of electron of metal then coupled the electron of metal and light generate the wave which passing in the metal gap waveguide. This wave is coupled in the (I and IV) regions in which wave is distribute in the three output port(O1,O2,O3). Main process are done in the region (II and III), only input applied in the region(I) and only output observed in the region (IV). The magnetic field and phase of input signal are same. The intensity of input signal denotes by the two state which is ”1” means the intensity of signal is high and ”0” means the intensity of signal is low. The refrative index of metal gap waveguide is 0.12 at frequency 1550nm and refrative index of air is 1. The refrative index of metal gap waveguide is varying at different frequency. When input signal(light) is a plane wave. Input light and output intensity can be written by equation 4.2 and equation 4.3

$$I_i = 0.5\sqrt{\frac{\varepsilon}{\mu}}|E_i|^2 \tag{4.2}$$

$$O_1 \propto |E_spp21|^2, O_2 \propto |E_spp22|^2, O_3 \propto |E_spp13|^2 \tag{4.3}$$

Here ε is the dielectric constant in air and μ is the magnetic permeability in air. $E_0i(i = 1, 2, 3)$ stand for electric field intensity the input light and $E_spps1i(i = 1, 2, 3)$ stand for the electric field intensity of SPPs at the end port of the region II. Input intensity of signal is depend upon the electric field and output intensity is depend upon the E_spp. Whole process occur at the interface of metal dielectric to form spp waves. Simulation on FDTD is not done without the propagate of spp waves.

4.2 AND Gate

The logic circuit of AND gate in FDTD is shown in figure 4.3. The coupling length of L1= 2000nm and L2= 1350nm. The length of regions (I and IV) is 500nm and 500nm. All parameter of logic AND gate cannot be change until all combination of AND gate are occur. Length of coupling is totally depend on the thickness of the input port, wavelength which are used, thickness of the space of metal and dielectric. Any parameter is change then change in the length of coupling. LASER light is applied at input port W1 and all combination of the AND gate applied at the other input port. The length of three metal gap

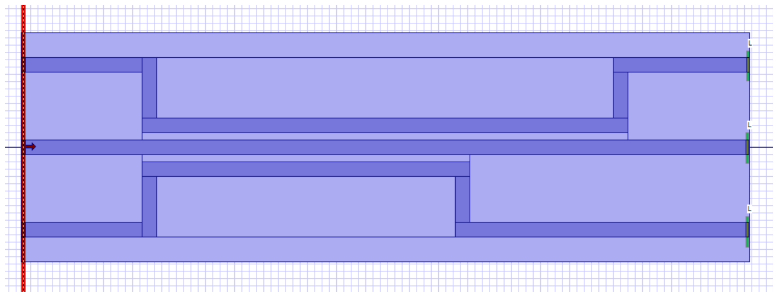


Figure 4.3: AND logic device

waveguide(D)=60nm and length of G1 is 30nm and length of G2 is 280 nm which used for avoid losses. Total length of all four regions is 3000nm. Total coupling length(L1 and L2) is 3250nm for D=60nm, G1=30nm at frequency 1550nm in figure 4.4.[14]

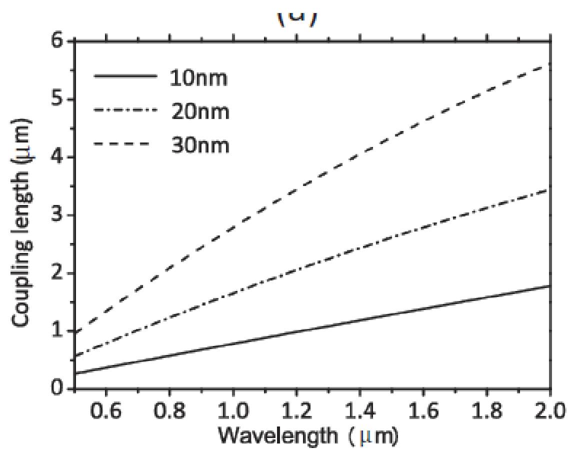


Figure 4.4: Coupling length vs Wavelength

Firstly we design the AND gate, input signal apply at the input port and position of input signal is varying according to the logic input. When input applied at the input port in circuit shown in figure 4.3, the light propagate in the metal gap waveguide shown in figure 4.5.

For AND gate input signal is fixed at input port W1. Two input signal is applied at other two input port. When input signal applied at the input port W1, it is always contribute in the coupling process in region(II and III). Other input signal applied at input port are same phase as well as no tilting angle. Power of input signal is 1 watt per meter. Amplitude

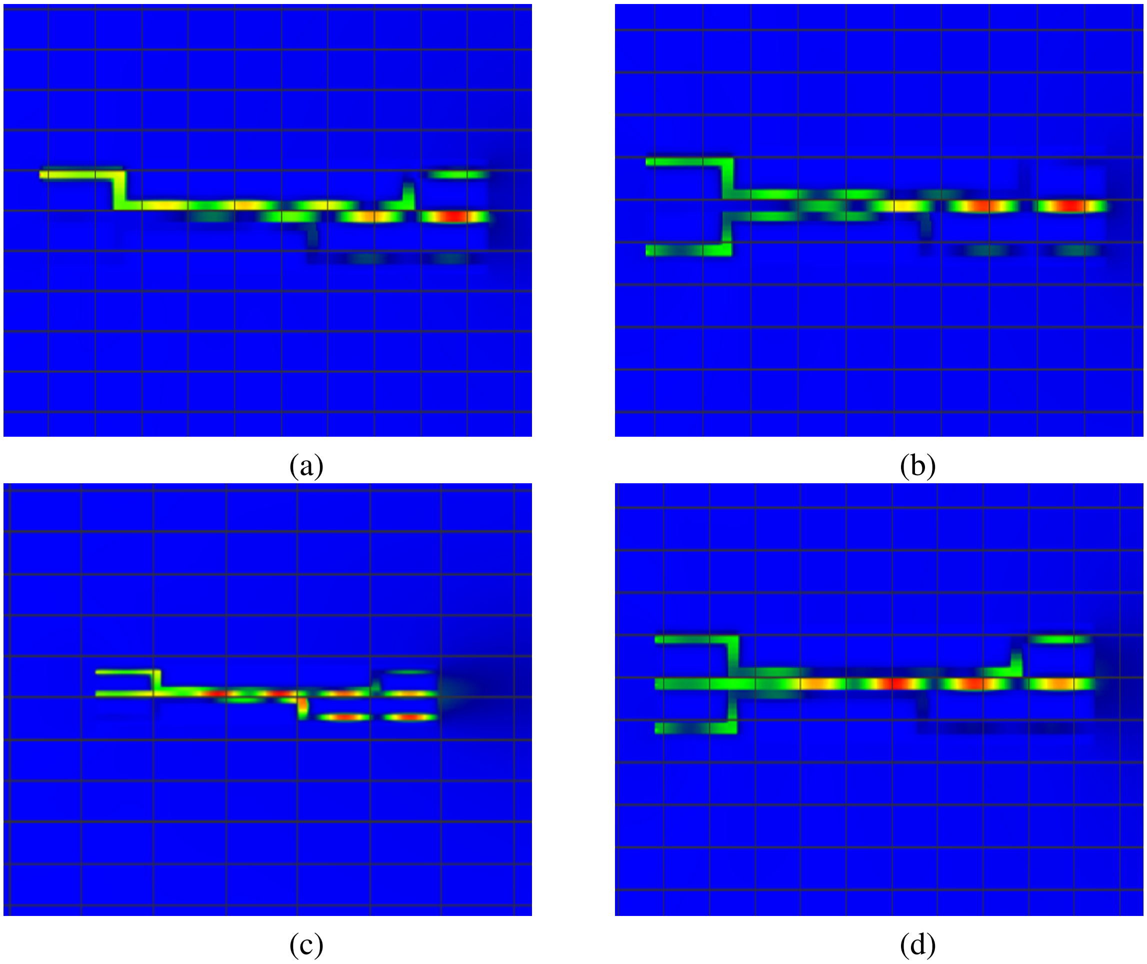
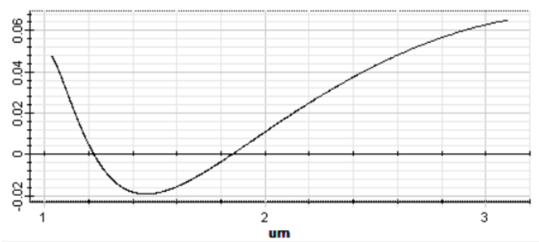
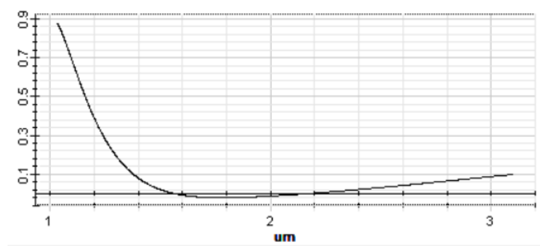


Figure 4.5: Light propagate in the AND Gate

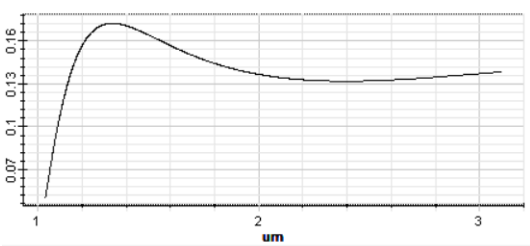
of input signal is 1 but it is not used on FDTD. Input signal is applied in the form of power. Intensity of output signal at the output port O1 is depend on the coupling length in the region(II and III) which is 3000nm. The intensity of output signal at the output port O1 is shown in figure 4.5. (a) Figure in which light signal applied only port W1 and no input signal applied at other input port. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other input port and distribute there power in the other metal gap waveguide and passing through region (IV) and obtained at output port O1. (b) Figure in which light signal applied at input port W1 and W3. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other signal. Most of signal passing through metal gap waveguide at output port O2. Then intensity of light is less obtained at the output port O1. (c) Figure in which light signal applied at input port W1 and W2. When it is enter the region(II and III) it is coupled with the other signal. Most of signal passing through metal gap waveguide at output port O2 and O3. Then intensity of light is less obtained at the output port O1. (d) Figure in which light signal applied at input port W1, W2 and W3. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other input signal which applied at input port W2 and W3.



(a)



(b)



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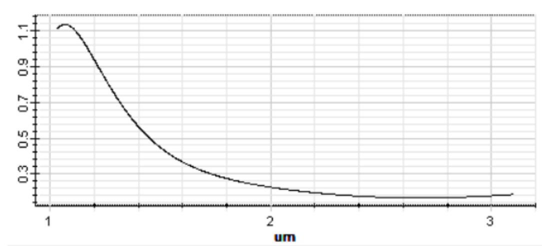


(d)

Figure 4.6: Output intensity vs Wavelength(micrometer)

In figure 4.6, (a) Figure in which light signal applied only port W1, no input signal applied at other input port and intensity of light at output port O1. Increase the wavelength of the input source, then decrease the output intensity of the signal at the output port O1 further increase output intensity of the signal and minimum output intensity of the signal at the 1400nm. Output intensity of the signal is negative value between 900nm to 1600nm. All output intensity are already in the normalized form. (b) Figure in which light signal applied at input port W1, W3 and intensity of light at output port O1. Increase the wavelength of the input source, then decrease the output intensity of the signal at the output port O1 and minimum output intensity of the signal at the 1800nm. Intensity of output signal always decrease. (c) Figure in which light signal applied at input port W1, W2 and intensity of light at output port O1. Increase the wavelength of the input source, then increase the output intensity of the signal at the output port O1 further decrease output intensity of the signal and minimum output intensity of the signal at the 1400nm and further increase the output intensity of the signal. (d) Figure in which light signal applied at input port W1, W2, W3 and intensity of light at output port O1. Increase the wavelength of the input source, then decrease the output intensity of the signal at the output port O1 and minimum output intensity of the signal at the 1800nm. Intensity of output signal always decrease. Output intensity at the output port O1 is normalized power. Output intensity of the AND gate is always measure at the output port O1. Vertical observation line is used for the measure of output intensity of light at output port O1. All logic are used in all gate is positive logic gate. It is means higher the intensity of signal represent by the logic ”1” and lower the intensity of signal represent by the logic ”0”. When both two input signal are logic ”0”, logic of output is ”0”. Any one signal is logic ”0”, then logic of output is ”0”. When both two input signal are logic ”1” then logic of output is ”1”. Signal passing through the metal gap waveguide in the form of Surface Plasmon Polaritons wave. This wave generate at the interface of metal dielectric and move along the interface of metal dielectric. AND gate is basic gate. AND gate is use in the digital device such that computer,mobile and other electronics device. AND gate is basic gate in digital circuit.

4.2.1 Observation

From the figure 4.6, we calculate the output intensity at output port O1. From table 4.3 ,we know the output intensity at output port O1. Input light at port W1, W2, W3 is I1, I2, I3.Input light I1 is always ”1” for the AND gate.

From using equation 4.2 and equation 4.3 we calculate the output intensity at the output port 01.[23]. Maximum value of output intensity of logic ”0” is 0.163(normalized output power). FDTD is simulation in the time domain. Minimum value of output intensity of logic ”1” is 0.455(normalized output power). The extinction ratio should be very high for logic gate. Value of extinction ratio is small that it is not good for logic gate.[24]. The log

Table 4.3: INTENSITY AND THE TRUTH TABLE OF AND GATE

I2	I3	Output Intensity at O1	Output logic
0	**0**	0.017	0
0	**1**	0.048	0
1	**0**	0.163	0
1	**1**	0.455	1

of ratio of Pon and Poff is called extinction ratios. Pon is represent to the lowest output intensity of output logic value "1", and Poff is represent to the highest intensity of output logic value "0". The extinction ratio of AND gate is 4.45 db. Intensity of output is measure at output port O1 using the observation vertical line which place at the output port O1. The extinction ratio is very low as compare to the extinction ratio of other logic gate.

4.3 OR Gate

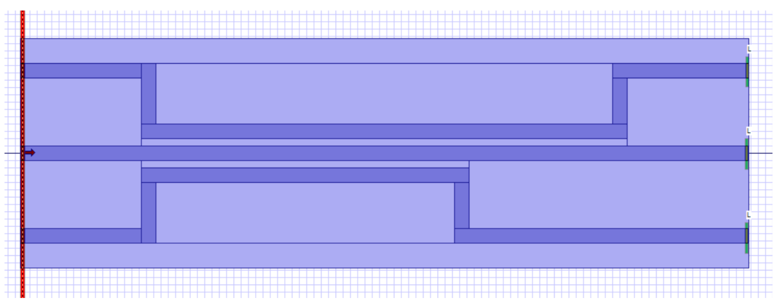
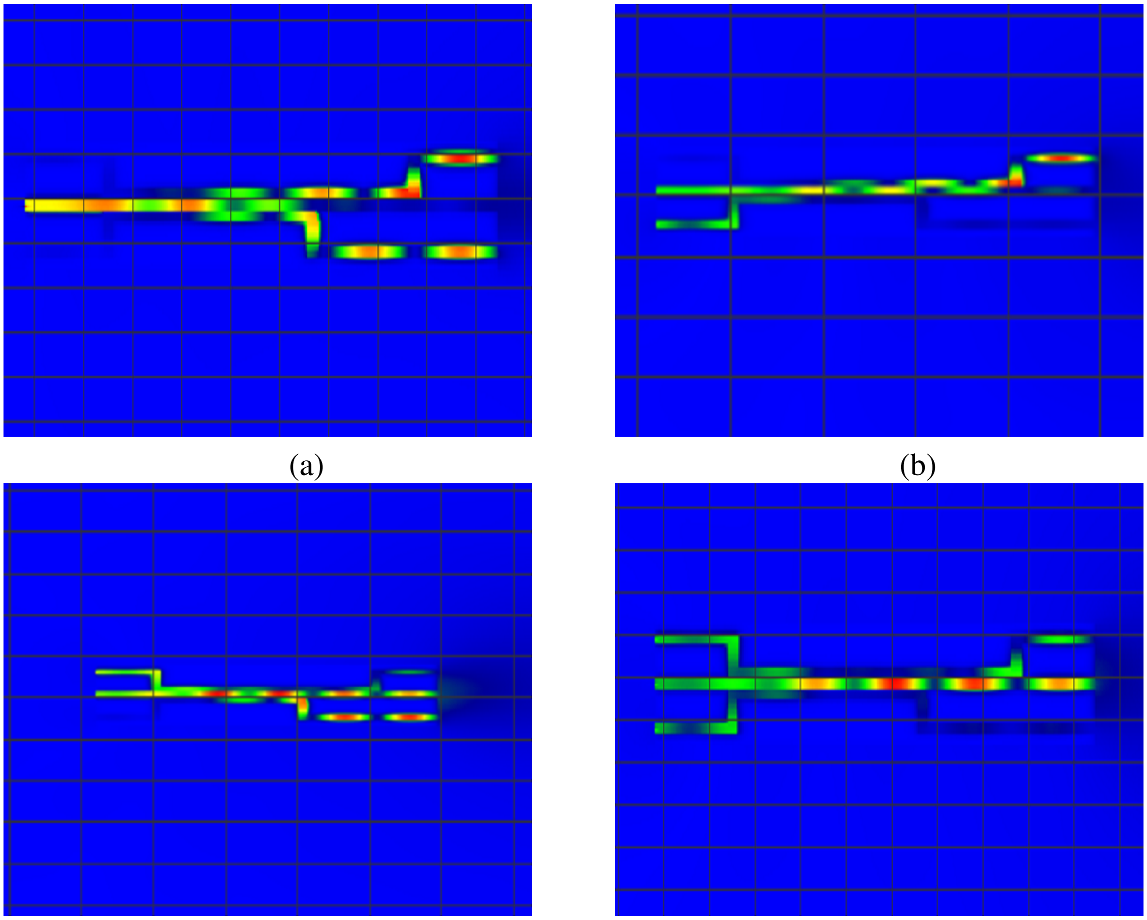


Figure 4.7: OR logic device

OR gate in above figure 4.7. Input signal which logic "1" is applied at input port W2 is fixed. Two input signal applied at input port W1 and W3. Any input signal are applied which is logic "1" then intensity of output is high at output port O2. The coupling length of L1= 2000nm and L2= 1350nm. All parameter of logic OR gate cannot be change until all combination of OR gate are occur. LASER light is applied at input port W2 and all combination of the OR gate applied at the other input port. The length of regions (I and IV) is 500nm and 500nm. The length of three metal gap waveguide(D)=60nm and length of G1 is 30nm and length of G2 is 280 nm which used for avoid losses. Total length of all four regions is 3000nm. Total coupling length(L1 and L2) is 3250nm for D=60nm, G1=30nm at frequency 1550nm.

All parameter are same as in AND gate. Calculation of output intensity is measure at output port O2. Simulation of OR gate when input signal applied at input port W1 and W3. Light is propagate in the three metal gap waveguide and there are coupled at the region (II and III). Intensity of input signal is distribute at the output port O1,O2,O3 in region (II and III) due to coupling process. For OR gate input signal is fixed at input port W2. Two input signal is applied at other two input port. Intensity of output signal at the output port O2 is depend on the coupling length in the region(II and III) which is 3000nm. When both two input signal are logic ”0”, logic of output is ”0”. Any one signal is logic ”0”, then logic of output is ”1”. When both two input signal are logic ”1” then logic of output is ”1”.Output intensity at the output port O2 is normalized power. Output intensity of the OR gate is always measure at the output port O2.Most of signal passing through metal gap waveguide at output port O1 and O2.

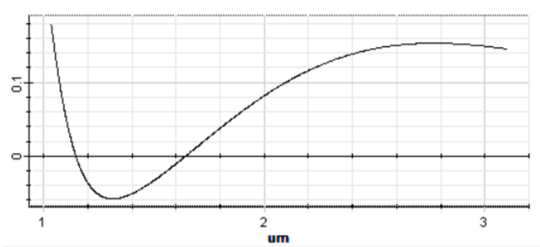
Figure 4.8 (a) Figure in which light signal applied only port W2 and no input signal applied at other input port. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other metal gap waveguide. Most of signal passing through metal gap waveguide at output port O1 and O3. Then intensity of light is less obtained at the output port O2. (b) Figure in which light signal applied at input port W2 and W3. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other input signal which applied at input port W2 and W3. Most of signal passing through metal gap waveguide at output port O1. Then intensity of light is less obtained at the output port O2 and O3. (c) Figure in which light signal applied at input port W1 and W2. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other input signal which applied at input port W2. Most of signal passing through metal gap waveguide at output port O2 and O3. Then intensity of light is less obtained at the output port O1.(d) Figure in which light signal applied at input port W1, W2 and W3. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other input signal which applied at input port W2 and W3.



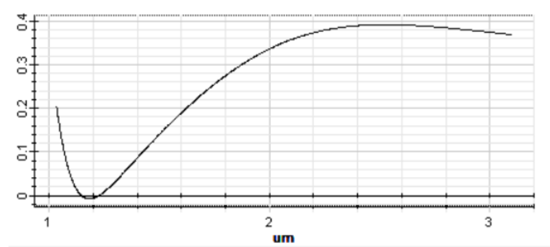
(a) (b) (c) (d)

Figure 4.8: Light propagate in the OR Gate

OR gate is use in the digital device such that computer,mobile and other electronics device. OR gate is basic gate in digital circuit. OR gate is used for design the half adder, full adder. XOR and XNOR gate is design using the AND and OR gate. All logic are used in all gate is positive logic gate. It is means higher the intensity of signal represent by the logic ”1” and lower the intensity of signal represent by the logic ”0”. In figure 4.9, (a) Figure in which light signal applied only port W2, no input signal applied at other input port and intensity of light at output port O2. Increase the wavelength of the input source, then decrease the output intensity of the signal at the output port O2 further increase output intensity of the signal and minimum output intensity of the signal at the 1300nm. Output intensity of the signal is negative value between 800nm to 1500nm (b) Figure in which light signal applied at input port W2, W3 and intensity of light at output port O2. Increase the wavelength of the input source, then decrease the output intensity of the signal at the output port O2 further increase output intensity of the signal and minimum output intensity of the signal at the 1200nm. (c) Figure in which light signal applied at input port W1, W2 and intensity of light at output port O2. Increase the wavelength of the input source, then increase the output intensity of the signal at the output port O2 further decrease output intensity of the signal and maximum output intensity of the signal at the 1300nm. (d) Figure in which light signal applied at input port W1, W2, W3 and intensity of light at output port O2. Coupling length is varying in different logic gate. Logic gate is depend on the coupling length. Increase the wavelength of the input source, then increase the output intensity of the signal at the output port O2 further decrease output intensity of the signal and maximum output intensity of the signal at the 1210nm.



(a)



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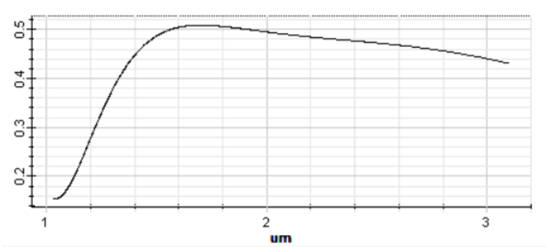

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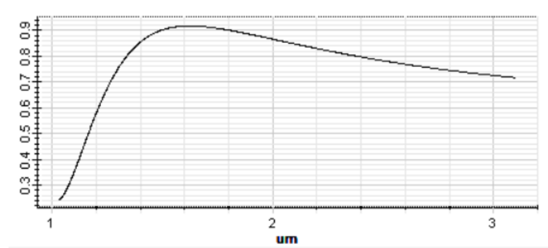


(d)

Figure 4.9: Output intensity vs Wavelength(micrometer)

4.3.1 Observation

From the figure 4.9, we calculate the output intensity at output port O2. From table 4.4 ,we know the output intensity at output port O2. Input light at port W1, W2, W3 is I1, I2, I3.Input light I2 is always ”1” for the OR gate.

Table 4.4: INTENSITY AND THE TRUTH TABLE OF OR GATE

I1	I3	Output Intensity at O2	Output logic
0	**0**	0.0017	0
0	**1**	0.191	1
1	**0**	0.468	1
1	**1**	0.902	1

From using equation 4.2 and equation 4.3 we calculate the output intensity at the output port 02. Maximum value of output intensity of logic ”0” is 0.0017(normalized output power). FDTD is simulation in the time domain. Minimum value of output intensity of logic ”1” is 0.191(normalized output power). The extinction ratio should be very high for logic gate. Value of extinction ratio is small that it is not good for logic gate. The log of ratio of Pon and Poff is called extinction ratios. Extinction ratio is increase in the OR gate. It is depend only the coupling length of the metal gap waveguide. The extinction ratio of OR gate is 20.50 db. Intensity of output is measure at output port O2 using the observation vertical line which place at the output port O2. The extinction ratio is high as compare to the extinction ratio of other logic gate. Extinction ratio is low then it is poor performance optical circuit. Extinction ratio is high then it is good performance optical circuit. ‘

4.4 XOR Gate

XOR gate in above figure 4.10 . Input signal which logic ”0” is applied at input port W1 is fixed. Two input signal applied at input port W2 and W3. Any input signal are applied which is logic ”1” then intensity of output is high at output port O3. The coupling length of L1= 1410nm and L2= 1200nm. The length of regions (I and IV) is 300nm and 300nm. The length of three metal gap waveguide(D)=60nm and length of G1 is 20nm and length of G2 is 280 nm which used for avoid losses. Total length of all four regions is 2010nm. Total

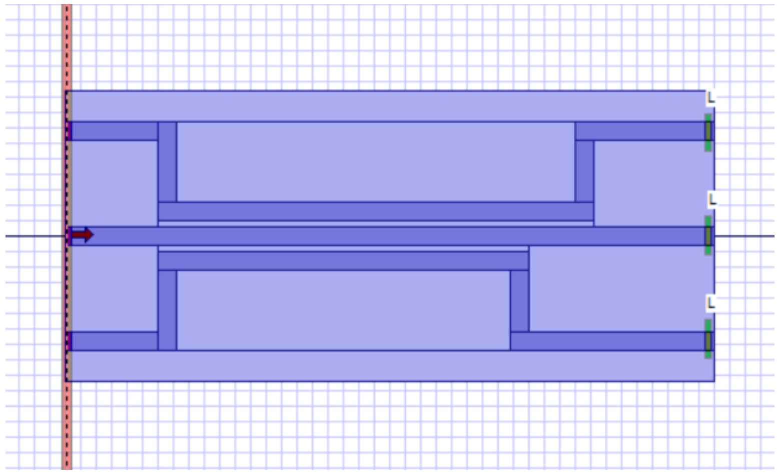


Figure 4.10: XOR logic device

coupling length(L1 and L2) is 2612nm for D=60nm, G1=20nm at frequency 1550nm. All parameter of logic XOR gate cannot be change until all combination of OR gate are occur. LASER light is not applied at input port W1 and all combination of the XOR gate applied at the other input port.

Figure 4.11 (a) Figure in which light signal applied only port W3 and no input signal applied at other input port. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other metal gap waveguide. Most of signal passing through metal gap waveguide at output port O3. Then intensity of light is less obtained at the output port O1 and O2. (b) Figure in which light signal applied at input port W2. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other metal gap waveguide. Most of signal passing through metal gap waveguide at output port O1 and O2. Then intensity of light is less obtained at the output port O3. (c) Figure in which light signal applied at input port W2 and W3. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other input signal which applied at input port W2 and W3. Most of signal passing through metal gap waveguide at output port O1 and O2. Then intensity of light is less obtained at the output port O3. The intensity of output signal at the output port O3. All parameter are same as in XOR gate. Calculation of output intensity is measure at output

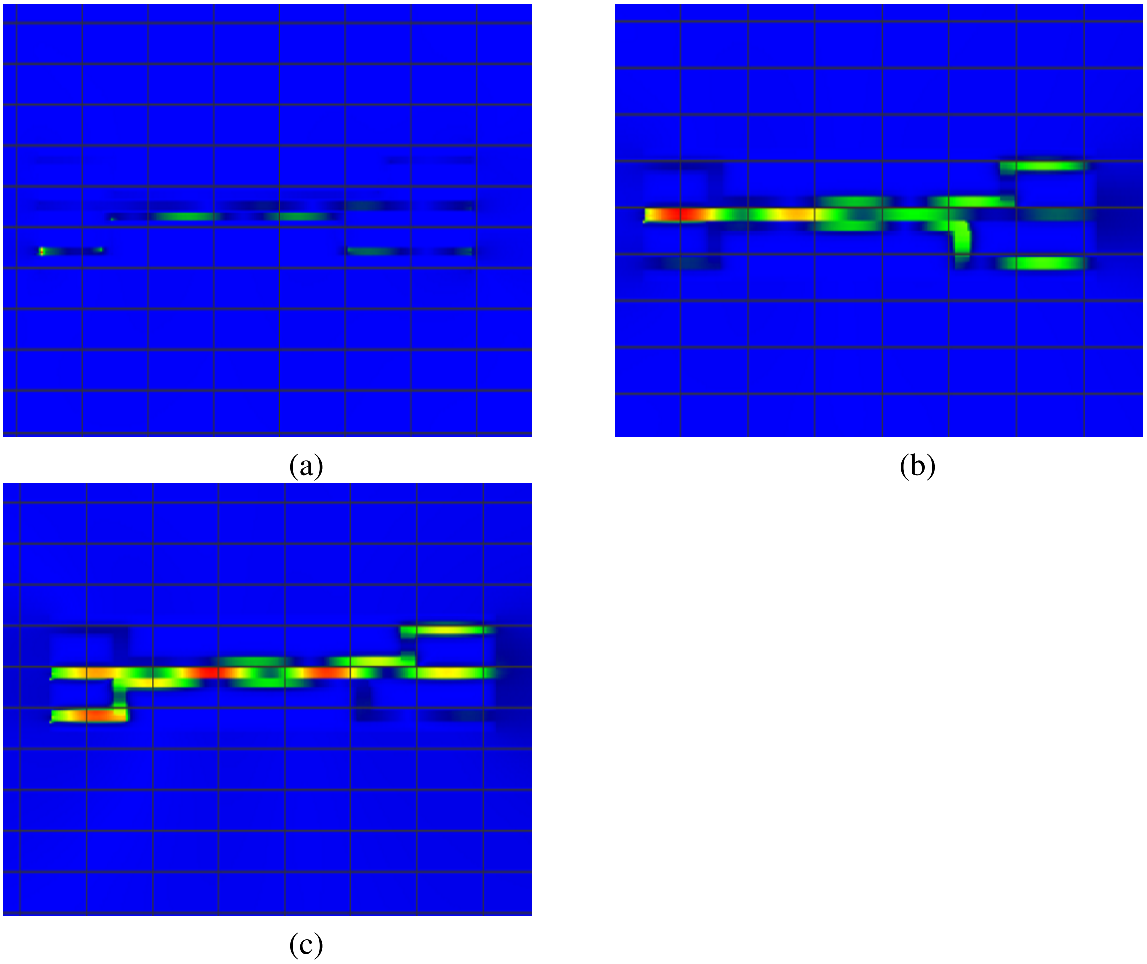


Figure 4.11: Light propagate in the XOR Gate

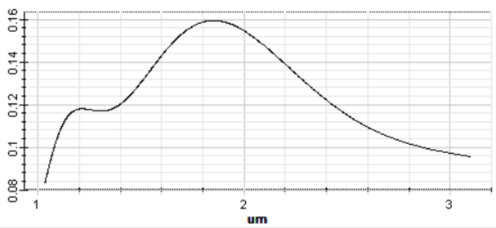
port O3. Simulation of XOR gate when input signal applied at input port W2 and W3. For XOR gate input signal is fixed at input port W1 which logic ”0”. Two input signal is applied at other two input port. Intensity of output signal at the output port O3 is depend on the coupling length in the region(II and III) which is 2612nm. When both two input signal are logic ”0”, logic of output is ”0”. Any one signal is logic ”0”, then logic of output is ”1”. When both two input signal are logic ”1” then logic of output is ”0”. Output intensity at the output port O3 is normalized power. Output intensity of the XOR gate is always measure at the output port O3.

XOR gate is used for design the half adder, full adder. Combination of AND, NOT, OR gate is called XOR gate. First case of XOR gate is all three input signal are logic ”0” which means no signal is applied at all three input port. No light passing through the metal gap waveguide during the simulation on the FDTD. In figure 4.12, (a) Figure in which light signal applied only port W3, no input signal applied at other input port and intensity of light at output port O3. Increase the wavelength of the input source, then increase the output intensity of the signal at the output port O3 further for sometime it is decrease output intensity of the signal and again it is increase and minimum and maximum output intensity of the signal at the 900nm and 1300nm. (b) Figure in which light signal applied at input port W2 and intensity of light at output port O3. Increase the wavelength of the input source, then decrease the output intensity of the signal at the output port O3 and minimum output intensity of the signal at the 800nm. (c) Figure in which light signal applied at input port W2, W3 and intensity of light at output port O3. Increase the wavelength of the input source, then increase the output intensity of the signal at the output port O3 and minimum output intensity of the signal at the 700nm. Output intensity of the signal is negative value between 700nm to 800nm. When no input signal applied at input port W1,W2,W3 then no output is obtained at output port O1,O2,O3. It is special case only present in the XOR gate. When increase the half width of input signal, light is not propagate properly in the there metal gap waveguide. Whole simulation in time domain because FDTD work is based on time domain. Only one input signal is logic ”1” then logic of output is ”1” at output port O3. When two input signal is same at input port W2, W3. Then output of signal is zero at output port O3 is shown in figure 4.12.

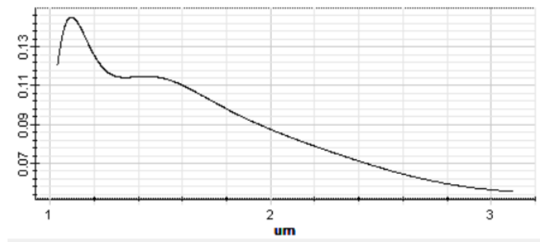
4.4.1 Observation

From the figure 4.12, we calculate the output intensity at output port O3. From table 4.5 ,we know the output intensity at output port O3. Input light at port W1, W2, W3 is I1, I2, I3.Input light I1 is always ”0” for the XOR gate.

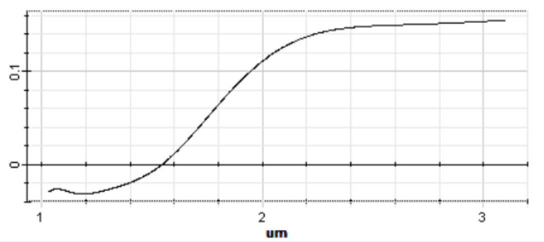
From using equation 4.2 and equation 4.3 we calculate the output intensity at the output port 03. Maximum value of output intensity of logic ”0” is 0.0008(normalized output power). FDTD is simulation in the time domain. Minimum value of output intensity of logic ”1” is 0.112(normalized output power). The extinction ratio should be very high for



(a)



(b)



(c)

Figure 4.12: Output intensity vs Wavelength(micrometer)

Table 4.5: INTENSITY AND THE TRUTH TABLE OF XOR GATE

I2	I3	Output Intensity at O3	Output logic
0	**0**	0	0
0	**1**	0.136	1
1	**0**	0.112	1
1	**1**	0.0008	0

logic gate. Value of extinction ratio is small that it is not good for logic gate. The log of ratio of Pon and Poff is called extinction ratios. Value of extinction ratio is different for each laogic gate. Performance of each logic gate is calculated by the value of extinction ratio. The extinction ratio of XOR gate is 21.46 db. Intensity of output is measure at output port O3 using the observation vertical line which place at the output port O3. The extinction ratio is high as compare to the extinction ratio of AND logic gate.

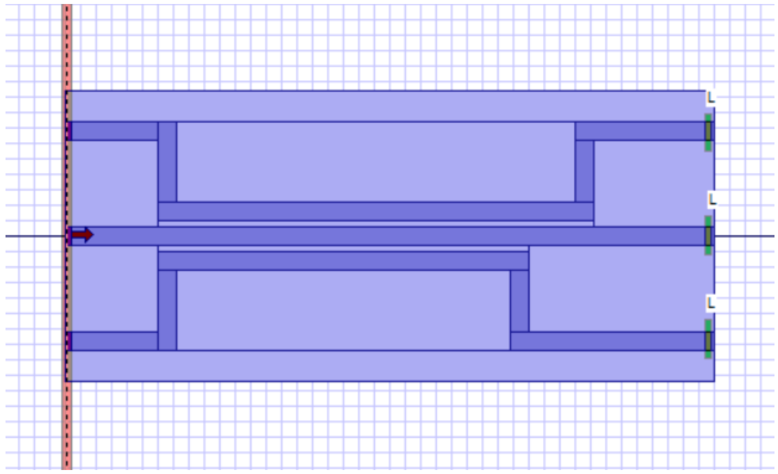


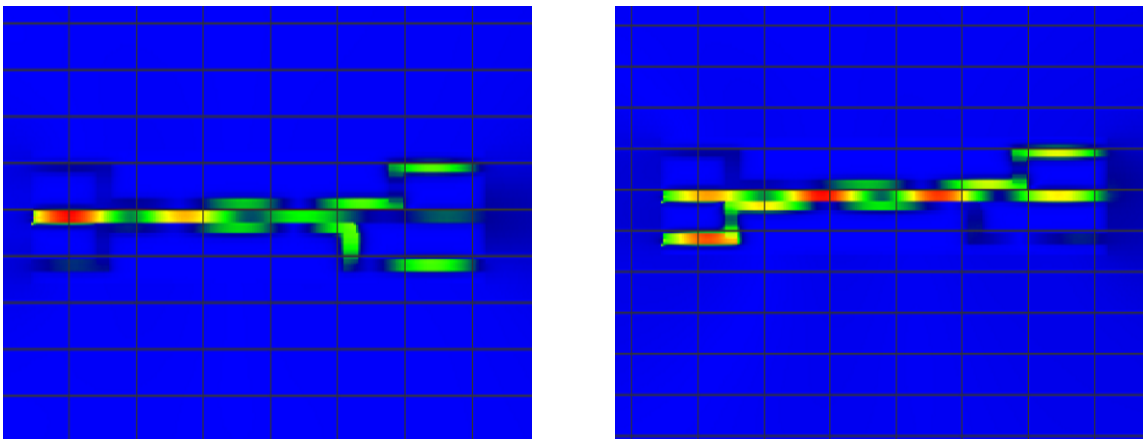
Figure 4.13: NOT logic device

4.5 NOT Gate

NOT gate in above figure 4.13 . Input signal which logic ”0” is applied at input port W1 and logic ”1” is applied at input port W2 is fixed. One input signal applied at input port W3. When input signal are applied which is logic ”1” then intensity of output is low at output port O3. When input signal are applied which is logic ”0” then intensity of output is high at output port O3. The coupling length of L1= 1410nm and L2= 1200nm. The length of regions (I and IV) is 300nm and 300nm. The length of three metal gap waveguide(D)=60nm and length of G1 is 20nm and length of G2 is 280 nm which used for avoid losses. Total length of all four regions is 2010nm. Total coupling length(L1 and L2) is 2612nm for D=60nm, G1=20nm at frequency 1550nm.

All parameter are same as in NOT gate. Calculation of output intensity is measure at output port O3. Simulation of NOT gate when input signal applied at input port W3 is shown in figure 4.14. For NOT gate input signal is fixed at input port W1 and W2. One input signal is applied at input port. (a) Figure in which light signal applied only port W2 and no input signal applied at other input port. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other metal gap waveguide. Most of signal passing through metal gap waveguide at output port O1 and O3. Then intensity of light is less obtained at the output port O2 (b)

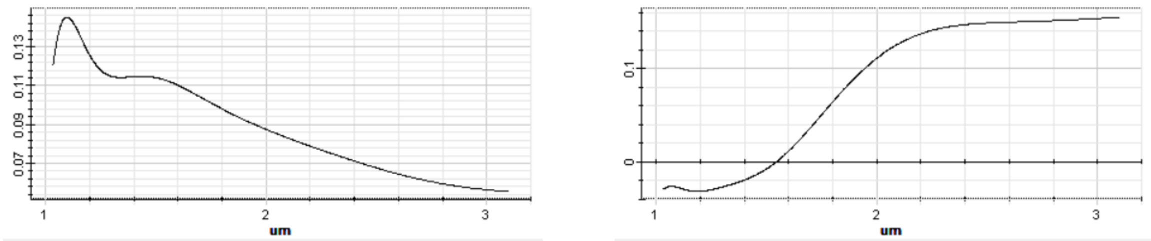
Figure in which light signal applied at input port W2 and W3. The intensity of output signal at the output port O3. Light passing through the region(I) without any interaction with other light. When it is enter the region(II and III) it is coupled with the other input port W3. Most of signal passing through metal gap waveguide at output port O1 and O2. Then intensity of light is less obtained at the output port O3 is shown in figure 4.14.



(a) (b)

Figure 4.14: Light propagate in the NOT Gate

In figure 4.15, (a) Figure in which light signal applied only port W2, no input signal applied at other input port and intensity of light at output port O3. Increase the wavelength of the input source, then increase the output intensity of the signal at the output port O3 and futher it is decrease the output intensity of the signal at the output port O3. Minimum output intensity of the signal at the 700nm. (b) Figure in which light signal applied at input port W2 and W3 and intensity of light at output port O3. Increase the wavelength of the input source, then increase the output intensity of the signal at the output port O3 and minimum output intensity of the signal at the 750nm. Output intensity of the signal is negative value between 770nm to 800nm. When no input signal applied at input port W1,W2,W3 then no output is obtained at output port O1,O2,O3. It is easily obtained in the single output port. Two input signal are used at the input port. It is special case only present in the NOT gate.



(a) (b)

Figure 4.15: Output intensity vs Wavelength(micrometer)

4.5.1 Observation

From the figure 4.15, we calculate the output intensity at output port O3. Input light I1 is ”0” and I2 is ”1” for the NOT gate.

Table 4.6: INTENSITY AND THE TRUTH TABLE OF NOT GATE

I3	Output Intensity at O3	Output logic
0	0.112	1
1	0.0008	0

From using equation 4.2 and equation 4.3. Maximum value of output intensity of logic ”0” is 0.0008(normalized output power). Minimum value of output intensity of logic ”1” is 0.112(normalized output power). The extinction ratio of NOT gate is 22.04 db. When G1 is 20nm then extinction ratio of XOR and NOT gate is 18.0db and 18.7db[22] but it increase to 21.46db and 21.46db in this thesis. When G2 is 30nm then extinction ratio of AND and OR gate is increase to 4.45db and 20.50db in this thesis. The extinction ratio of all four logic gate are given table 4.7.

Table 4.7: EXTINCTION RATIO OF AND, OR, XOR, NOT GATE

LOGIC GATE	EXTINCTION RATIO(db)[22]	EXTINCTION RATIO(db)(In this thesis)
AND	4.1	4.45
OR	11.1	20.50
XOR	18.0	21.46
NOT	18.7	21.46

Chapter 5

Conclusion and Future Work

The Properties of propagating surface plasmon polaritons (SPPs) have been investigated which is along one-dimensional metal structures for more than 20 years and Propagating SPPs are best potential way to construct next-generation circuits. All four logic gate are design with high extinction ratio. We design the multifunction logic gate with minimum size. The size of logic gate in the micrometer. The coupling size is 2 micrometer $\times$ 0.7 micrometer in the region (II and III). It is further reduce to construct the ultrasmall logic gate. All logic gate are design in this paper with the high extinction ratio and improve there performance. Coupling length, thickness of metal gap waveguide, thickness of the coupling metal are fixed for the design the AND and OR gate. In this thesis, Whole process are depend upon the coupling length. Coupling length, thickness of metal gap waveguide, thickness of the coupling metal are fixed for the design the XOR and NOT gate. Changing the Coupling length, thickness of metal gap waveguide, thickness of the coupling metal for design the different logic gates.

Silver whose frequenc dependent complex relative permittivity is characterized by the Drude model. Relative permittivity of silver is change according to the change in wavelength. Silver is good choosen as a metal for design the optical nanoscale circuit. The optical constants n and k for the noble metals (silver, copper and gold) in the range of 0.5eV-6.5eV at the room temperature. Different material are used for the design the logic gate provide the different extinction ratio of logic gate. The coupling length is totally depend upon the thickness of metal gap waveguide, thickness of the coupling metal and wavelength. In this thesis four region are used for the design the logic gate . Many region are used for the design the logic gate. It is depend on the requirement. Extinction ratio of logic gate are calculate is high in this thesis. This all logic gate is used in the high density circuit due to there ultrasmall size. Further it is increase by changing the Coupling length, thickness of metal gap waveguide, thickness of the coupling metal and wavelength.

5.1 Scope of future work

Design the logic gate in form of V-shaped structure to reduced propagation loss. Many materials are used for design the logic gate such that silver and gold. When gold is used as a metal for design the logic gate reduce to propagation loss. Metal-dielectric-metal, metal-metal-dielectric, dielectric-dielectric-metal geometry are used for design the logic gate. We design the full adder and full subtractor in Mach–Zehnder interferometers based on the nonlinear effect. This technology further improve in incoming days. Less propagation loss are present in the optical device using this technology. Any optical device are design by using this technology in the high density circuit. Design the Nanoplasmonic wavelength demultiplexing (WDM) structures based on metal-insulator-metal waveguides at the 1550nm in which different wavelength are passing through the same channel. It is used in the communication system. We also design the resonant cavity with the help of metal-dielectric structure. We can reduce the losses by using gold material as a metal. But gold is very costly. All logic gate are verified by the FDTD with the help of MATLAB coding. Full adder, half adder, full subtractor and half subtractor circuit are design in the metal-dielectric-metal structure.

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