

Waveguide Design Strategies for Surface Plasmon Resonance

Badrinathan S¹, Dinesh N²

^{1,2} UG Student, Department of Electronics and Communication Engineering,
Prince Shri Venkateshwara Padmavathy Engineering College, Tamilnadu, India

ABSTRACT

This paper deals with the design and implementations of waveguide focusing on SPR. Sub-wavelength holes in a gold film deposited in SiO₂ substrate has been created and the transmission through the holes is analyzed. Surface Plasmon wave that results from the periodic array of holes will enhance the transmission in a certain wavelength region. The width of the square holes is varied (100nm, 150nm, 200nm, 250nm) and the results are analysed.

Keyword: - waveguide, sub-wavelength, substrate, surface plasmon wave.

1. INTRODUCTION

A waveguide is a structure that guides waves, such as electromagnetic waves or sound, with minimal loss of energy by restricting expansion to one dimension or two. This is a similar effect to waves of water constrained within a canal, or why guns have barrels that restrict hot gas expansion to maximize energy transfer to their bullets. Without the physical constraint of a waveguide, waves are decreasing according to the inverse square law as they expand into three-dimensional space.

There are different types of waveguides for each type of wave. The original and most common meaning is a hollow conductive metal pipe used to carry high frequency radio waves, particularly microwaves.

The geometry of a waveguide reflects its function. Slab waveguides confine energy in one dimension, fiber or channel waveguides in two dimensions. The frequency of the transmitted wave also dictates the shape of a waveguide: an optical fiber guiding high-frequency light will not guide microwaves of a much lower frequency. As a rule of thumb, the width of a waveguide needs to be of the same order of magnitude as the wavelength of the guided wave. Some naturally occurring structures can also act as waveguides. The SOFAR channel layer in the ocean can guide the sound of whale song across enormous distances.

2. SURFACE PLASMON RESONANCE

Surface Plasmon Resonance (SPR) is a physical process that can occur when plane-polarized light hits a thin metal film under total internal reflection conditions.

2.1 Total Internal Reflection

When a light beam hits a half circular prism, the light is bent towards the plane of interface, when it is passing from a denser medium to a less dense medium. Changing the incidence angle (θ) changes the out-coming light until it reaches a critical angle. At this point, all the incoming light reflects within the circular prism. This is called total internal reflection (TIR). Although no light is coming out of the prism in TIR, the electrical field of the photons extends about a quarter of a wavelength beyond the reflecting surface.

2.2 Surface Plasmons

Now the prism is coated with a thin film of a noble metal on the reflection site. In most cases, gold is used because it gives a SPR signal at convenient combinations of reflectance angle and wavelength. In addition, gold is chemically inert to solutions and solutes typically used in biochemical contexts. When the electrical field energy of the photon is just right, it can interact with the free electron constellations in the gold surface. These are the outer shell and conduction-band electrons. The incident light photons are absorbed and the energy is transferred to the electrons, which convert into surface plasmons.

Photon and electron behaviour can only be described when they have both wave and particle properties. In accordance with the quantum theory, a plasmon is the particle name of the electron density wave. Therefore, when in a TIR situation the quantum energy of the photons is right, the photons convert to plasmons leaving a 'gap' in the reflected light intensity.

2.3 Working of SPR

Surface Plasmon Resonance is a phenomenon that occurs when polarized light hits a metal film at the interface of media with different refractive indices. SPR techniques excite and detect collective oscillations of free electrons (known as surface plasmons) via the Kretschmann configuration. Light is focused onto a metal film through a glass prism and the subsequent reflection is detected. At a certain incident angle (or resonance angle), the plasmons are set to resonate with light, resulting in absorption of light at that angle. This creates a dark line in the reflected beam shown in fig -1.

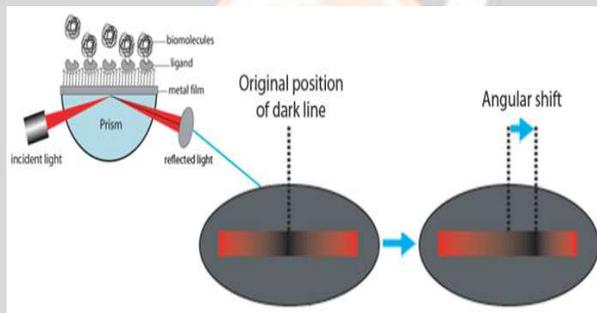


Fig -1: Original dark band and shift in dark band

The excitation of surface plasmons results in a dark line in the reflected beam, and the angular position of the dark line shifts as a molecule binding event takes place. That dark line contains a wealth of information. The resonance angle can be obtained by observing a dip in SPR reflection intensity. fig -2 shows a shift in the reflectivity curve which represents a molecular binding event taking place on or near the metal film, or a conformational change in the molecules bound to the film. By monitoring this shift vs. time, researchers can study molecular binding events and binding kinetics without the hassle of labels. SPR Scanning Angle Response. SPR causes an intensity dip in the reflected light at the sensor surface. A shift in the curve represents molecular binding.

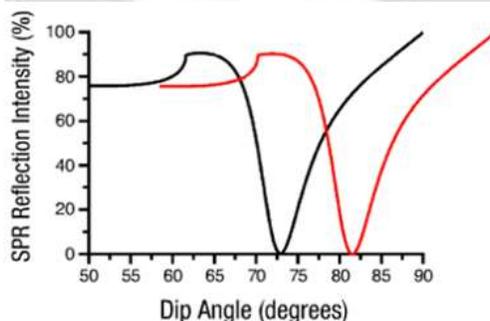


Fig -2: Shift in reflectivity curve

3. WAVEGUIDE SIMULATION

The Opti-fdtd 32-bit tool contains the following namely opti-fdtd designer, opti-fdtd simulator and opti-fdtd analyser.

- i. Layout Designer - This is where you define your structure and simulation conditions.
- ii. Profile Designer - This is used to define the materials and profiles used in the simulation.
- iii. Simulator - This program loads the designer file and performs the simulation. The simulator is started from the layout designer.
- iv. Analyzer - This program is used to view the results and perform some post processing. As soon as the simulation is done, the simulator will ask if you would like to open the analyzer.

3.1 Layout Design

The following steps are followed to design the layout:

- 1) Waveguide profile (waveguide cross section) and material profile
 - i) Profile: Channel_Au; Width: 0.425; Thickness: 0.425; Offset:0; Material: Gold Au Lorentz Drude Model.
 - ii) Profile: Channel_Air; Width: 0.2; Thickness: 0.2; Offset: 0; Material: Air.
 - iii) Profile: Channel_SiO2; Width: 0.425; Thickness: 0.425; Offset:0; Material: n= 1.5.
- 2) Simulation domain properties
 - i) Width: 0.2; Profile: Channel_SiO2
 - ii) Length: 1.0 μ m (z-direction); Width: 0.425 μ m (x-direction)
 - iii) Substrate layer thickness: 0 μ m (y-direction); Material: Air
 - iv) Cladding thickness: 0.425 μ m (y-direction); Material: Air
- 3) Draw Linear Waveguide
 - i) Profile: Channel_SiO2; Start: 0.425; End: 0.425; Width: 0.425 (x-direction waveguide thickness); Depth: 0 (y-direction original point); Taper type: Linear; Start horizontal offset: 0.6 (z-direction start); Start vertical offset: 0 (x-direction start); End horizontal offset: 1.0 (z-direction start); End vertical offset: 0 (x-direction start).
 - ii) Profile: Channel_Au; Start: 0.425; End: 0.425; Width: 0.425 (x-direction waveguide thickness); Depth: 0 (y-direction); Taper type: Linear; Start horizontal offset: 0.4 (z-direction start); Start vertical offset: 0 (x-direction start); End horizontal offset: 0.6 (z-direction start); End vertical offset: 0 (x-direction start).
 - iii) Profile: Channel_Air; Start: holewidth; End: holewidth; Width: holewidth (x-direction waveguide thickness); Depth: 0.425/2-holewidth/2 (y-direction); Taper type: Linear; Start horizontal offset: 0.399 (z-direction start); Start vertical offset: 0 (x-direction start); End horizontal offset: 0.6 (z-direction start); End vertical offset: 0 (x-direction start).
- 4) VB Script


```
dim dWit
for i= 1 to 4
select case i
case 1
dWit= 0.100
case 2
dWit= 0.150
case 3
dWit= 0.200
case 4
dWit= 0.250
end select
ParamMgr.SetParam"holewidth", dWit
WGMgr.Sleep 500
ParamMgr.Simulate
Next
```
- 5) Input wave setup
 - i) Input plane: Vertical input

- ii) Select Gaussian Modulated Continuous Wave. (The Gaussian Modulated CW tab appears.)
- iii) Wavelength (um): 0.68(um)
- iv) Gaussian Modulated CW
 - 1. Time offset (sec.): 0.8e-14
 - 2. Half width (sec.): 0.1e-14
- v) General tab
 - 1. Input Field Transverse: Rectangular (windowed plane wave)
 - 2. Z Position: 0.2 Plane
 - 3. Geometry: Positive direction
 - 4. Label: InputPlane1 (default)
- vi) 3D Transverse
 - 1. Centre Position X: 0.0 (); Halfwidth X: 0.5()
 - 2. Centre Position Y: 0.4125 (); Halfwidth Y: 0.5()
 - 3. Effective index: Local
 - 4. Polarization: Linear Y
 - 5. Amplitude: 1.0 (V/m²)
- 6) Observation Area:

The observation area appears as shown in fig -3 when the parameters for the observation area are defined.

 - i) Centre Horizontal Offset (z-direction): 0.1(um); Centre Vertical Offset (x direction): 0.0(um); Centre depth (y-direction): 0.2125 (um); X-Length 0.425 (um); Y-Length 0.425 (um); Label: ObservationArea1; Data Components Ex, Ey, Hx, Hy.
 - ii) Centre Horizontal Offset (z-direction): 0.8(um); Centre Vertical Offset (x direction): 0.0(um); Centre depth (y-direction): 0.2125 (um); X-Length 0.425 (um); Y-Length 0.425 (um); Label: ObservationArea2; Data Components Ex, Ey, Hx, Hy.

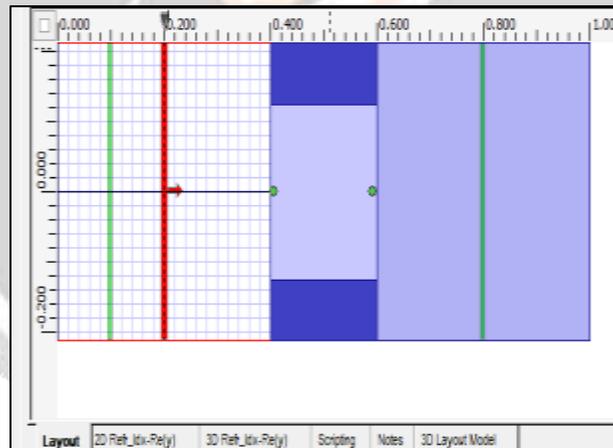


Fig -3: Observation area

- 7) Simulation Parameter
 - i) Type the following values for the mesh size:
 - Mesh Delta X(m): 0.005
 - Mesh Delta Y(m): 0.005
 - Mesh Delta Z(m): 0.005
 - ii) Run for 12000-time steps.
 - iii) Set input key field as input plane 1 and wavelength 0.68.
 - iv) Click Run button to start the simulation.

3.2 Results and Analyses

The results are obtained by using Opti FDTD Analyser software.

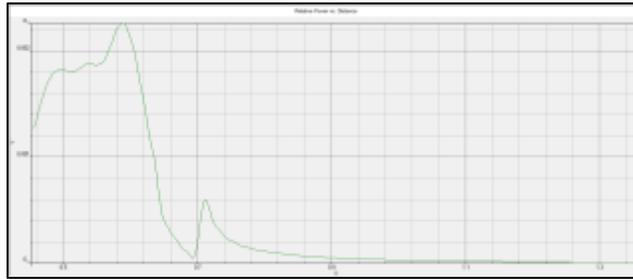


Fig -4: Power vs Layout distance for 100nm

The electrical and magnetic field of the waveguide with a hole size of 100nm for each coordinate is analysed. The power spectrum for waveguide with hole size 100nm is shown in fig -4

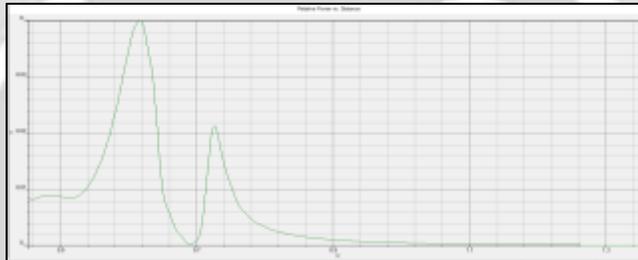


Fig -5: Power vs Layout distance for 150nm

The electrical and magnetic field of the waveguide with a hole size of 150nm for each coordinate is analysed. The power spectrum for waveguide with hole size 150nm is shown in fig -5.

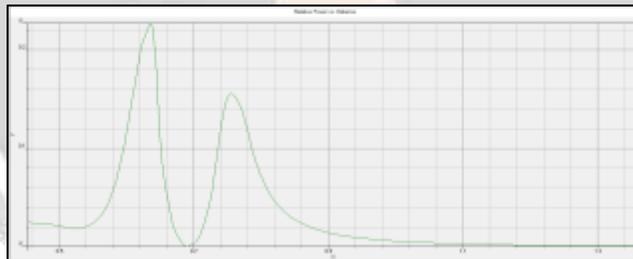


Fig -6: Power vs Layout distance for 200nm

The electrical and magnetic field of the waveguide with a hole size of 200nm for each coordinate is analysed. The power spectrum for waveguide with hole size 200nm is shown in fig -6.



Fig -7: Power vs Layout distance for 250nm

The electrical and magnetic field of the waveguide with a hole size of 250nm for each coordinate is analysed. The power spectrum for waveguide with hole size 250nm is shown in fig -7.

4. CONCLUSION

Waveguide focusing on surface plasmon resonance had been designed and implemented. Sub wavelength hole has been created on gold film deposited on the SiO₂ substrate. The holes in the gold film will enhance the transmission in the certain wavelength region. Then the width of the square holes is varied and the results are analyzed.

5. REFERENCES

- [1]. Dengpeng Yuan, Tianjianli, Ying Dong and Yujinliu “Design of high performance micro integrated surface plasmon resonance sensors based on silicon-on-insulator Rib waveguide array”, 2015.
- [2]. Ishimaru, A. Jaruwatanadilok, S. and Kuga, Y. “Generalized surface plasmon resonance sensors using metamaterials and negative index materials”.
- [3]. He, J.J. Li, M.Y. Xiong, X.H. Zhang and W. Zhu, L.P. “A sensitive bi-reflection surface plasmon resonance waveguide sensor based on SiON”, 12th International Conference on Optical Communications and Networks (ICOON), pp. 1–3, 2013.
- [4]. Chauhan, K. K. Goswami and N. Saha, A. “Analysis of surface plasmon resonance-based bimetal coated tapered fiber optics sensor with enhanced sensitivity through radially polarized light”, Opt. Comm. vol.379, pp. 6–12, 2016.