Design and Analysis of Plasmonic Antenna for Nanoscale Wireless Applications

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Abstract. The paper demonstrates design and analysis of plasmonic antenna for nanoscale wireless links. A surface plasmon polarities (SPP’s) based Hybrid Metal Insulator Metal (HMIM) based circular nano patch antenna for optical frequencies are designed and analysed using commercially available CST Microwave studio suite. The proposed circular patch antenna operated in the optical frequency band of 225 THz to 245 THz with a bandwidth of 20 THz. The overall size of the optical antenna is 1500 x 1000 nm². The proposed antenna is very much useful in chip scale applications, interconnects and optical sensing applications.

1. Introduction

The requirement for high-speed optical transmission needs travelling far distances of light guidance on scales lower than wavelengths. Integrated photonic waveguide devices provide very less loss and minimal diffraction [1-4]. Due to less loss the engineers will develop the new nano-scale structures and system for various applications. Among various nano components, the nano antennas are playing a vital role in controlling and radiating light at nanometer range. Various basic antennas like dipole, bowtie, yagi-uda, horn, Vivaldi, rectangular patch and metallic slits etc. [5-11], are designed and analysed in the previous literature. Due to directional radiation patterns, patch antennas are best suitable for link between waveguide components. Among various waveguides used in nano scale applications hybrid plasmonic waveguide gives better efficiency with low losses. Previously, nano patch antennas had poor efficiency and high ohmic losses due to that these are not practically realizable [12-15]. The performance of the hybrid plasmonic waveguides based nano patch antenna are improved further by multi-layer structures [16-25].

In this paper, HMIM based nano circular patch antenna with waveguide feeding is designed and analyzed. The proposed antenna is possible for fabricate on semiconductor fabrication procedure techniques. The layers are deposited one by one using e-beam lithography processing. The nano circular patch antenna is operated in the frequency range of 225 – 245 THz with S11<-10db and the bandwidth of 20 THz.

The paper organization as follows, section 2 describes the antenna design parameters and implementing nano patch using HMIM waveguide. The simulation results and optimized results are included in the section 3. Finally, the paper ends with the suitable conclusion.
2. Circular Nano Patch Antenna Design

The HMIM waveguide [23] taken for designing circular patch antenna shown in figure 1. The HMIM waveguide made up of low-high-low dielectrics between two metal layers. Silver is used as metal and their characteristics taken from the Drude’s model [26]. PTFE and AlGaAs is used as a low and high dielectric material. The $t_h$, $t_m$ and $t_s$ is used as high dielectric, metal and low dielectric material thickness. $L_a$ and $a$ are taken as feed length and width. $R$ is taken as radius of the circular patch. $L$ and $W$ are length and width of the layers. The dimensions of the proposed circular nano patch antenna are included in table 1. The nano circular patch antenna is designed and simulated using commercially available full wave simulation technology i.e CST studio suite. The simulation environment taken as perfect matched layer conditions. The overall size of the mesh is 5 nm x 5 nm.

![Fig.1. circular nano patch antenna (a) front view (b) Three-dimensional](image)

| S.No | Parameter | Dimensions in nm |
|------|-----------|------------------|
| 1    | $L$       | 1500             |
| 2    | $a$       | 60               |
| 3    | $R$       | 350              |
| 4    | $W$       | 1000             |
| 5    | $L_a$     | 150              |
| 6    | $t_h$     | 150              |
| 7    | $t_m$     | 100              |
| 8    | $t_s$     | 20               |
| 9    | hslab     | 200              |
| 10   | hsub      | 150              |

The overall foot print area of the proposed antenna is 1500 x 1000 nm$^2$. The dispersion properties of the HMIM waveguide generally tells about the broad band behavior. The field distributions observed for the wide band and the energy confines on the spacer regions [25-26].

The proposed HMIM waveguide fed circular nano patch antenna is very much compatible to semiconductor fabrication technology. The fabrication can be done layer by layering process. All layers are deposited using magnetron sputtering and the completer structure is done by using e-beam lithography techniques.
3. Results and Discussion

The commercially available FDTD solver-based CST studio suite is used for the design and simulation of the proposed nano circular patch antenna. The mesh size used for the antenna simulation is 5 nm x 5 nm under PML boundary conditions. The $S_{11}$, VSWR and radiation characteristics are used for the analysis purpose of the antenna. The figure 2 represents the $S_{11}$ of the antenna. By varying the feed width in steps of 10 nm of the antenna, the $S_{11}$ moves to the right shown in figure 2. The optimized dimensions of the width are 60 nm.

![Fig. 2. Reflection Coefficient of the circular nano patch antenna](image)

Figure 3 represents the VSWR of the proposed circular nano patch antenna. The VSWR of the antenna less than 2 from the frequency range of 225 THz-245 THz. The radius of the circular patch is also playing a dominant role in changing the $S_{11}$ and VSWR values.

![Fig.3. VSWR of the circular nano patch antenna](image)
The radiation characteristics of the circular nano patch antenna is represented in figure 4. The three dimensional and two-dimensional view of the radiation patterns are represented in figure 4 (a) and (b) respectively. The radiation patterns observed at the frequency of 238.38 THz.

![Figure 4](image)

**Fig.4.** Radiation patterns (a) Three dimensional and (b) two dimensional for the circular nano patch antenna at 238.38 THz

The gain versus frequency of the circular nano patch antenna is represented in figure 5. The gain ranges from 4.5 dB to 6 dB from 225 THz to 245 THz. The gain is increasing as frequency increases.

![Figure 5](image)

**Fig.5.** Gain versus Frequency plot

The proposed antenna is suitable of nanoscale applications of high bandwidth and stable radiation characteristics. This type of antennas is fabricated using the e beam lithography technology.

4. Conclusion

In this paper, a waveguide fed circular nano patch antenna using HMIM waveguide is analysed and proposed for optical frequencies. The proposed antenna size is 1500 nm x 1000 nm. The proposed antenna size is very less comparing other photonic antennas. The circular nano patch antenna gives the
bandwidth of 25 THz with stable radiation characteristics. The proposed circular nano patch antenna is best suitable for photonic applications.

References
[1] Sreevardhan CH, Venkata Ratnam D and Hima Sree B 2018 AEU-Int. J. Electronic and Comm. 94 179
[2] Subba Reddy V, Siva Ganga Prasad M, Madhav B T P 2017 J Adv. Res. Dynamic Control Sys 9 SP-14
[3] Subba Reddy V, Siva Ganga Prasad M, Madhav B T P 2017 Int. J. Control Theory Applications 8.
[4] Subba Reddy V, Madhav B T P, Prathyusha S, Janardhan G G, Kalpanath N and Rao M V 2017 ARPJ. Sci Engg. 12 4483
[5] Madhav B T P, Subba Reddy V, Reddy D R and Rao M V 2018 Int. J. Engg. Tech. 7 333
[6] Subba Reddy V, Prasad M S G, Madhav B T P 2019 Int. J. Innovative Tech Exploring Engg 8 2278
[7] Subba Reddy V, Vipul Agarwal, Prasad M S G, Madhav B T P 2019 Int. J. Engg Advance Tech. 8 2249.
[8] Subba Reddy V, Prasad M S G, Madhav B T P 2019 Int. J. Adv Trends Computer Science Engg. 8 2278
[9] Saad-Bin-Alam M, Khalil M I, Rahman A and Chowdhury AM 2015 IEEE Photon Technol Lett 27 1092
[10] Yousefi L 2015 PIER Lett 50 85
[11] Yousefi L and Foster AC 2012 Opt Express 20 18326
[12] Kashyap N, Wani Z A, Jain R, Khusboo and Dinesh Kumar V 2014 Appl Phys A Mater Sci Process 117 725
[13] Cubukcu E, Kort E A, Crozier K B and Capasso F 2006 Appl Phys Lett 89 093120
[14] Brongersma M L 2008 Nature Photonics 2 270
[15] Bakker R M, Yuan H K, Lui Z, Drachev V, Kildishev A V, Shalaev V M, Pederson R H, Gresillon S and Boltasseva A 2008 Appl Phys Lett 92 043101.
[16] Silveira G N M, Wiederhecker G S and Figueroa H E H 2013 Opt Express 21 1234
[17] Dregely D, Taubert R, Dorfmuller J, Vogelgesang R, Kern K and Giessen H 2011 Nat Commun 2 1038
[18] Singh R, Rockstuhl C, Menzel C, Meyrath TP, He M, Giessen H, Lederer F and Zhang W 2009 Opt Express 17 9971
[19] Pan Z and Guo J 2013 Opt Express 21 32491
[20] Grosjean T, Movelle M, Burr G W and Baida F I, Opt Express 21 1762
[21] Ramaccia D, Bilotti F, Toscano A and Massaro A 2011 Opt Lett 36 1743
[22] Ooi K J A, Bai P, Gu M X and Ang L K 2011 Opt Express 19 17075
[23] Sharma P and Kumar V D 2016 Electronics Lett 52 732
[24] Sharma P and Kumar V D 2018 IEEE Photon Technol Lett 30 959
[25] Sharma P and Kumar V D 2017 IEEE Photon Technol Lett 29 1360
[26] Maier S A 2017 Plasmonics: Fundamentals and applications. Springer Science New York chap 2 p 25–28