

Wideband Wire-Grid Nano-Antenna Array for Optical Wireless Communications

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Abstract—This paper presents an eleven-elements wire-grid nano-antenna array designed for optical communications applications. The array radiates a highly directive linearly polarized wave along the broadside direction with enhanced bandwidth resulting from the different lengths of the inner radiator and the outer ones. The antenna also has the advantage of its low backside lobe levels and low cross-polarization levels across the E - and H - planes. The high radiation performance of the proposed array makes it suitable for point-to-point inter-/intra-chip optical communications applications.

I. INTRODUCTION

Nano-scale devices are being manufactured due to ongoing advancements in fabrication technology. Plasmonic devices, having dimensions in the nano scale, received lots of attention. They are able to bridge the size gap between electronic and photonic devices. Nano-antenna, an example of plasmonic devices, has various applications including bio-medical sensing [1], energy harvesting [2], imaging [3], and optical communications [4]. A number of nano-antenna topologies have been presented in the literature. This includes, but not limited to, torus-shaped [5], nano-dipoles [6], bow-tie [7], and dielectric resonators [8]. In order to enhance the antenna's performance, arrays of these elements should be constructed. Wire-grid nano-antenna is one example of such arrays [4], [9]. It consists of a number of radiators connected together through a number of wire connectors. The length of each radiator or connector is approximately half guided wavelength in order to maximize the antenna's directivity. At optical frequencies, where metals exhibit significant losses, this type of array is promising due to its compact size compared to conventional arrays. The reduced area contributes to a significant improvement in radiation efficiency. However, the primary drawback of this array is its inherently narrow bandwidth [10].

II. STRUCTURE OF WIRE-GRID ARRAY

In this work, an eleven-element wire-grid nano-antenna array, shown in Fig. 2, is presented. The nano-rods constructing the antenna are made of silver and have length corresponding to half guided wavelength. These rods are fed by coupled nano strips line and are placed on top of SiO_2 thin layer. Beneath the SiO_2 layer, a silver ground plane is incorporated to eliminate backside radiation, enabling the antenna to be placed on any substrate without compromising its performance. The antenna operates as follows: the coupled nano-strip line is excited in its odd (differential) mode, inducing currents that flow in the same direction along the radiators, resulting in

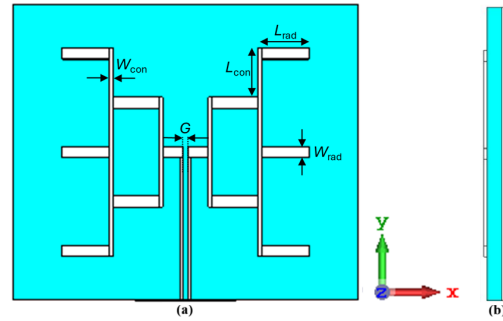


Fig. 1. Structure of the proposed wire-grid nano-antenna array: (a) top-view, and (b) side-view.

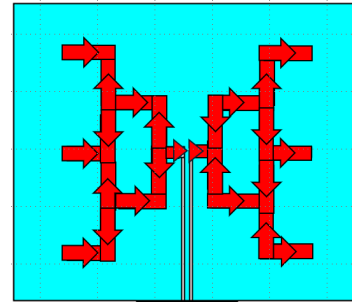


Fig. 2. Current distribution configuration along the radiators and connectors of the wire-grid antenna array.

constructive radiation. In contrast, the out-of-phase currents along the connectors cancel their radiation. By carefully tuning the lengths and widths of the radiators and connectors, the antenna's directivity can be optimized. Fig. 2 shows the current distribution along radiators and connectors, demonstrating constructive interference between horizontal radiators oriented along the x -axis and destructive interference between vertical connectors along the y -axis."

The antenna was optimized using CST software. The thickness of silver nano-rods is kept fixed at 30 nm. The list of the design parameters of the proposed array is as follows: $L_{\text{rad}} = 380$ nm, $W_{\text{rad}} = 90$ nm, $L_{\text{con}} = 395$ nm, $W_{\text{con}} = 30$ nm, and $G = 40$ nm. It is worth mentioning that the radiators' lengths are longer compared to the connectors' lengths, even though both values correspond to half the guided wavelength. This discrepancy can be attributed to the significant influence of the rod widths on the guided wavelength, as previously investigated in [4].

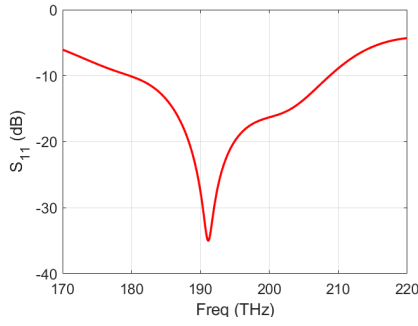


Fig. 3. Reflection coefficient of the wire-grid array.

III. RESULTS AND DISCUSSION

The performance of the proposed antenna is investigated using CST software. Drude's model is used to calculate the dielectric permittivity of silver at optical frequencies. The simulation results demonstrated that the antenna has a wide impedance bandwidth of 29 THz (14.93%) ranging from 179.7 THz up to 208.7 THz, as shown in Fig. 3. It is evident that the antenna exhibits two intersecting resonances, which can be attributed to the structural difference between the central radiator, consisting of two $\lambda_g/4$ dipoles, and the other radiators, which are $\lambda_g/2$ dipoles. The 3D radiation pattern of the proposed array is shown in Fig. 4. The antenna shows a high directivity with value of 13.2 dBi at 193.55 THz. The calculated radiation efficiency of the array is 60%. Losses are mainly attributed to silver metallic losses at optical frequencies. The 2D radiation patterns are illustrated in Fig. 5. The array is characterized by its high polarization purity along both E - and H - planes. The maximum cross-polarization level along these planes is below -37 dB. This advantage can be used to double the information capacity of the communication system by assigning orthogonal polarizations to the same frequency. Due to the small effective aperture of the proposed antenna, its communication range is limited to very short distance. For example, this antenna is well-suited for inter- and intra-chip communications as an alternative to conventional transmission lines. This adds the advantage of decreasing the metallic losses which increase exponentially with the propagation distance, making transmission lines highly inefficient for long-distance signal transfer. In contrast, wireless wave propagation experiences losses proportional to $\frac{1}{r^2}$, which are significantly lower compared to the losses in wired connections.

IV. CONCLUSION

In this paper a directive nano-antenna wire-grid array of eleven radiators is presented. The array operates over a wide bandwidth allowing for high-speed data communications between chips. The directivity of the array can be further enhanced by increasing the number of radiators. However, this comes at the cost of reduced radiation efficiency and the requirement for more space. To achieve optimal performance,

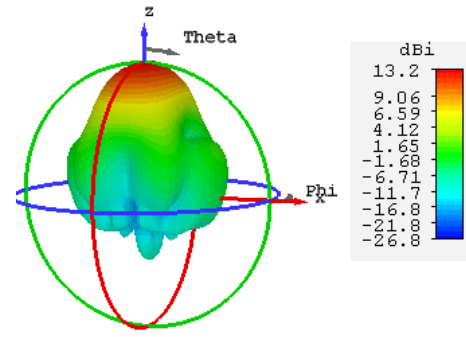


Fig. 4. 3D radiation pattern of the wire-grid antenna array at 193.55 THz.

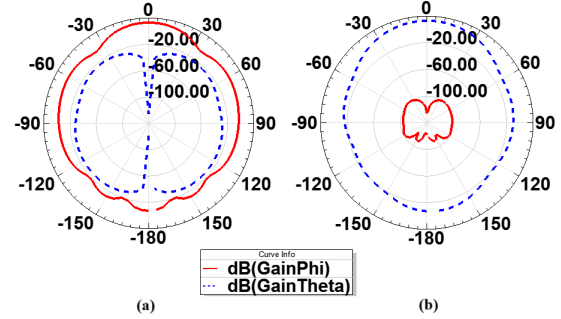


Fig. 5. 2D radiation pattern of the wire-grid antenna array at 193.55 THz (a) E -plane, and (b) H -plane.

an optimization process can be employed to determine the ideal number of radiators that maximizes the array's gain.

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