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COMPARATIVE ANALYSIS OF SILVER AND GRAPHENE BASED METASURFACE UNIT-CELL STRUCTURE FOR WIDEBAND THz ANTENNA

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ABSTRACT

The rapid growth of wireless communication is accelerating like never before. It is propelled by the introduction of the devices that uses 5G and beyond. It is foreseeable that the antennas in THz range, smart antennas and reconfigurable intelligent surfaces (RIS) are going to be vital in the future. A lot of traction is happening in the THz frequency range with the amalgamation of the THz antennas based off of metasurface integrations. In this paper a metasurface based THz antenna is designed using 2 different materials and their performance is evaluated and compared. The unit cell structure is made up of silver and graphene materials and geometries are modified for the patch antenna. The improved performance of graphene over silver is obtained and the results are presented in a novel and comparably comprehensible manner.

Keywords: metasurface, planer-antennas, THz-antennas, Unit-cell.

INTRODUCTION

Metasurface is a two-dimensional (2D) artificial material that is designed to manipulate light in a specific way (Anand et al., 2014). Unlike conventional materials, the properties of a metasurface are determined by the shape, size, and arrangement of its constituent subwavelength building blocks, rather than by its bulk material properties. This allows metasurfaces to perform advanced optical functions, such as beam steering, wavefront manipulation, polarization control, and light absorption (Bala & Marwaha, 2016), (George & Madhan, 2017).

Metasurfaces have attracted a lot of attention in recent years due to their potential applications in various fields, including optics, photonics, telecommunications, and imaging. They have been used to create flat lenses, holograms, beam steering devices, and other optical devices with improved performance and compact size. The unique properties of metasurfaces have the potential to revolutionize many areas of science and technology.

TERAHERTZ ANTENNAS

The evolution of terahertz (THz) antennas (Kaur et al., 2018) has been driven by the increasing demand for new and improved THz communication and imaging technologies (Khan et al., 2019, 2020). THz antennas play a critical role in these technologies by converting electrical signals into THz radiation and vice versa. The following is a brief overview of the evolution of THz antennas:

Early THz Antennas: Early THz antennas were primarily metal horn antennas, which were simple in design and limited in their frequency range. They were mainly used for laboratory experiments and provided low directivity and gain (Koenig et al., 2013).

Lens Antennas: Lens antennas, such as spherical and parabolic lenses, were later developed to improve the directivity and gain of THz antennas. These lenses focus the THz radiation into a smaller beam, allowing for better signal transmission and reception (Mrunalini & Manoharan, 2017).

Slot Antennas: Slot antennas, which consist of a thin metal sheet with a small slot cut into it, were introduced for THz applications. They offer high directivity and gain, and are capable of operating over a wide frequency range.

Metasurface Antennas: More recently, metasurface antennas have been developed, which consist of a thin layer of engineered materials that can manipulate THz radiation in various ways. These antennas are capable of controlling the phase and polarization of THz radiation, leading to improved performance and new functionalities (Prabhu et al., 2019), (Prabhu & Pandian, 2021b, 2021a).

Miniaturized Antennas: The trend towards miniaturization and integration of THz systems has led to the development of compact and highly integrated THz antennas. These antennas are designed for use in portable and wearable THz devices and systems.

The continued development of THz antennas is expected to lead to new and improved THz technologies, including faster and more reliable communication systems, more advanced medical imaging systems, and improved security and surveillance systems.

METASURFACE BASED ANTENNAS

Metasurface antennas find inspiration and roots from metamaterial-based antennas for gain enhancements and other feature implementations (Sharma & Kaur, 2023a, 2023b) Metasurface-based antennas (Shubham et al., 2022) have undergone significant evolution over the years, driven by advancements in materials science, nanotechnology, and computational design methods (Suganya, Prabhu, et al., 2023). Here are some key developments in the evolution of metasurface-based antennas:

1) Early Developments: Metasurface-based antennas were first introduced in the early 2000s as an alternative to traditional antennas that used resonant metal structures. Metasurfaces offered the advantage of being able to manipulate the phase and amplitude of the incoming electromagnetic waves in a controlled and precise manner.

2) Single Layer Metasurfaces: Early metasurface-based antennas were based on a single layer of subwavelength scatterers, which allowed for the control of the phase of the incident wavefront. These antennas were mainly used for beam steering and polarization control (Suganya, Pushpa, et al., 2023).

3) Multilayer Metasurfaces: With the advancement of nanotechnology, it became possible to stack multiple layers of subwavelength scatterers to create more complex and versatile metasurface-based antennas. Multilayer metasurfaces allowed for the manipulation of both the phase and amplitude of the incident wavefront (Thampy et al., 2015), enabling new applications such as absorption and reflection control (Prabhu & Pandian, 2021b, 2021a), (Mrunalini & Manoharan, 2017).

4) Machine Learning-Based Design: With the advent of machine learning and artificial intelligence, it has become possible to use computational methods to optimize the design of metasurface-based antennas. Machine learning-based design has enabled the creation of more sophisticated and efficient metasurface-based antennas that can perform multiple functions.

5) Integrated Metasurface Antennas: With the advancement of semiconductor technology, it has become possible to integrate metasurfaces directly into mobile electronic devices for energy harvesting by manipulating the electromagnetic waves (Mrunalini & Manoharan, 2017). This has opened up new possibilities for compact, low-cost, and high-performance antennas that can be integrated into consumer electronics.

METHODOLOGY

The design inspiration of the antenna presented in the paper comes from improvement in the gain-bandwidth performance parameter at terahertz frequency. The objective of this improvement will facilitate the communication in 6G THz communication. The simulation setup for this paper is done in ANSYS Electronics Desktop 2021R. The experimental simulation consists of design of a simple microstrip patch antenna of gold with the ground plane of gold material also. The microstrip patch antenna with slots is designed to enhance bandwidth, therefore corner rectangular slots are placed on the edges of the antenna and they have resulted in increased gain-bandwidth performance. The selection of material is extremely important for THz applications and range as with the rise of frequency practical heating effects become way too prominent to handle for simple materials like copper. The viable options for microstrip patch antenna of the dimension length 216µm X breadth 256µm for substrate and 120 µm X 160 µm patch. are gold, PEC and graphene/graphene powder mixed with gold. In this simulation scenario a metasurface unit cell array structure of silver is tested for THz range. The gold patch antenna is then modified with slots on the edges of the patch in the second step. The introduction of slot offers the advantages discussed in the previous section viz high directivity, gain and enhanced bandwidth. In the third modification step, the silver based metasurface unit cell array is replaced with the graphene based metasurface unit cell array structure. Graphene is a very popular choice of creating metasurface unit cells. The slotted patch antenna is shown in Figure 1. The metasurface unit cell is shown in Figure.2 The geometry of the unit cell is square and dimension of each unit cell is 20 µm X 20 µm. The height of metasurface unit cell is 1 µm. A cylindrical cutout slot of 5 µm radius is made in the centre and a small patch of 4 µm X 4 µm square patch is placed in the centre. The silver metasurface unit cell array is shown in Figure.3. The graphene based metasurface unit cell array is shown in Figure.4.

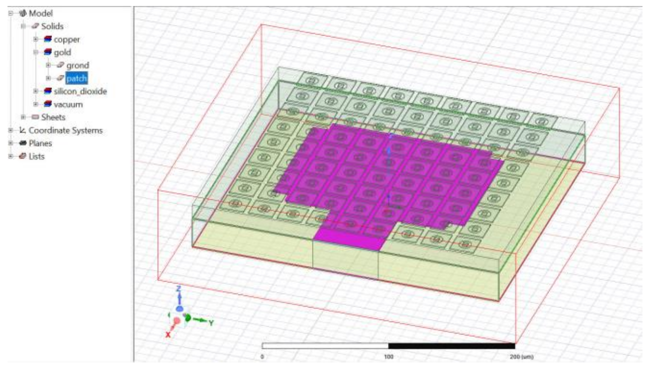

Figure 1: Slotted gold patch antenna for THz wideband frequency.

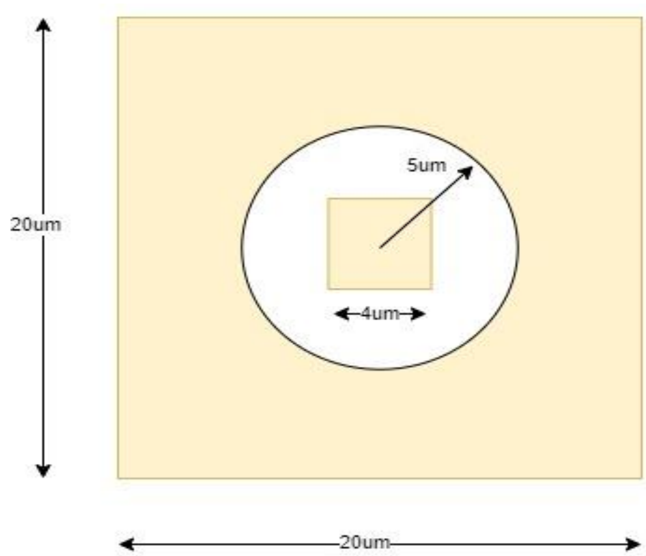

Figure 2: Unit Cell structure with dimensions.

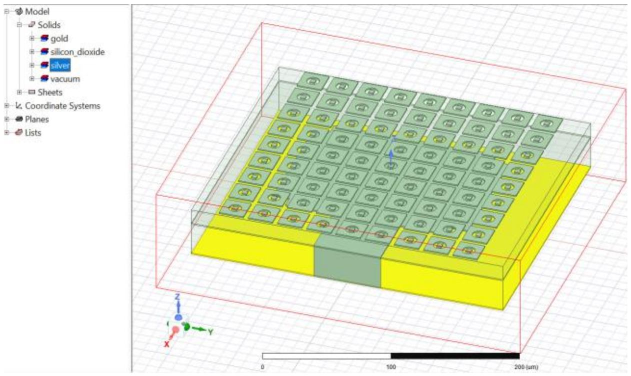

Figure 3: Silver Metasurface array on slotted patch

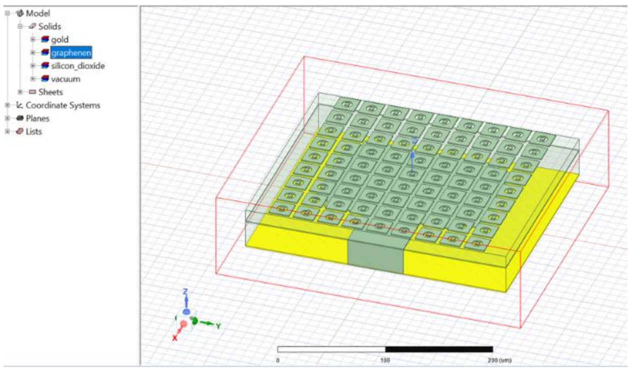

Figure 4: Graphene Square Metasurface array on slotted patch

RESULTS AND OBSERVATIONS

It is observed that slotted patch microstrip antenna improves the bandwidth slightly for the silver metasurface. However, it improves the bandwidth more prominently when the metasurface is graphene based. The effective communication in case of graphene metasurface based antenna starts at 1.37 THz as shown in Figure.6 as opposed to 2.05 THz of silver-based counterpart as shown in Figure.5 The enhanced bandwidth of graphene based metasurface antennas can give us wider operational range up to its 10 THz with 6 resonant frequencies of interest. The best performance for graphene based metasurface antenna is – 28.44dB at resonant frequency of 5.73 THz. However, the best performance for a silver based metasurface antenna is -23.55dB at resonant frequency of 8.57THz.

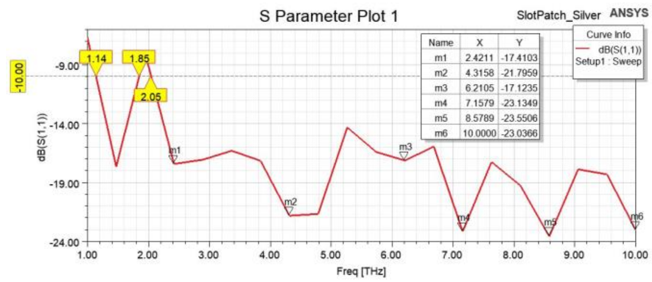

Figure 5: S11 parameter plot for Antenna with Slotted Microstrip gold patch with Silver Metasurface for THz frequency range.

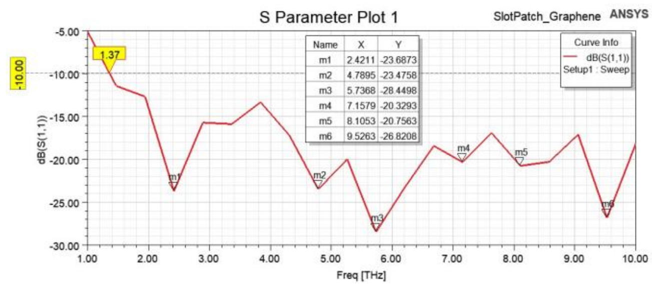

Figure 6: S11 parameter plot for Antenna with Slotted Microstrip gold patch with graphene Metasurface for THz frequency range.

Table 1 S11 parameter comparison of Silver and Graphene based metasurface on gold patch

Freq [THz]	dB(S(1,1)) [Silver]	Freq [THz]	dB(S(1,1)) [Graphene]
2.42	-17.41	2.42	-23.68
4.78	-21.64	4.78	-23.47
5.73	-16.39	5.73	-28.44
7.15	-23.13	7.15	-20.32
8.10	-19.24	8.10	-20.75
9.52	-18.29	9.52	-26.82

CONCLUSION AND FUTURE SCOPE

In this paper, a modified slotted patch antenna is proposed with graphene metasurface. The modification is done over the silver based metasurface structure and it has resulted in increased bandwidth and improved S11

parameters over the enhanced operating bandwidth. The graphene based metasurface has resulted in enhanced performance for five out of six resonant frequency points i.e. 2.42 THz, 4.78 THz, 5.73 THz, 7.15 THz, 8.10 THz and 9.52 THz. Considering, an enhanced bandwidth of 0.68THz and an application range of 1.37 THz to 10 THz, the graphene based metasurface antenna gives
-6.276dB better performance for 1st resonant frequency of 2.42 THz,
-1.83 dB better performance for 2nd resonance frequency of 4.78THz,
-12.05dB better performance at 3rd resonance frequency of 5.73THz,
-1.51dB better performance on 5th resonant frequency of 8.10 and
-8.52 dB better performance at 6th resonance frequency of 9.52 THz.

It gives an exception at 5th resonance frequency of 7.15 THz where it underperforms. The graphene based metasurface cell unit can be modified geometrically to enhance the performance parameters further. The THz antennas in the frequency range of 3THz to 10 THz find practical applications in very high data rate communications that is classified under 6G. The next generation of internet classified as Web3 will have very high data requirements because of futuristic metaverse sensor devices like smart wearables, where only antennas such as THz antenna discussed in the paper is required. Further they find applications where antennas need ultra small integration e.g. for miniaturized satellites. They also find applications in very high rate switching and remote sensing of close objects. Frequencies in the range of 3 THz to 7THz are pivotal in low-latency broadband applications as bandwidth of only half a THz can suffice very large data rates for metaverse kind of applications.

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