Design and Fabrication of Terahertz (THz) Antenna Using Aerosol Jet Printing

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Abstract— **Terahertz (THz) technology has emerged as a promising field for various applications, including imaging, spectroscopy, and wireless communication. However, designing and fabricating terahertz antennas presents several challenges, such as material selection, fabrication precision, and integration with other components. This paper presents the design, fabrication, and characterization of a compact microstrip terahertz antenna with dimensions of 3mm x 2mm, leveraging Aerosol Jet Printing (AJP) technology, which enables the direct printing of functional materials with high resolution and accuracy, for its fabrication. The proposed antenna was designed for operation in a specific terahertz frequency range, considering the dielectric properties of the substrate and conductive properties of the printed metallic layer. We performed simulations to optimize the antenna's performance, followed by the fabrication process using AJP. The fabricated antenna was characterized by measuring its radiation pattern, gain, and return loss, demonstrating satisfactory performance in the targeted frequency range. The results indicate that AJP technology is a viable and efficient approach for fabricating terahertz antennas with high precision and reduced complexity, potentially paving the way for further advancements in terahertz technology and its applications.**

I. Introduction

Terahertz (THz) technology is increasingly garnering interest from scientists and engineers globally, owing to its significant potential in applications like high-resolution radars, imaging systems, sensing, security scanning, and high-speed communications [1]-[10]. Antennas play a crucial role in these applications. In recent times, various THz antennas have been developed, including horn antennas, slotted waveguide antennas, reflector antennas, and dielectric lens antennas [11]-[28]. Dielectric lens antennas are highly appealing for numerous THz applications due to their straightforward design, high gain, wide bandwidth, absence of conductor losses, and circular polarization [19]-[25].

THz technology, spanning frequencies from 0.1 THz to 10 THz, has garnered significant interest in recent years due to its potential applications in various fields, such as imaging, spectroscopy, wireless communication, and security systems. The development of efficient and reliable terahertz antennas is crucial for the advancement of these applications. However, designing and fabricating terahertz antennas presents several challenges, including material selection, fabrication precision, and integration with other components. Microstrip antennas offer several advantages, such as low profile, lightweight, and ease of integration with other electronic components, making them attractive candidates for terahertz applications.

The conventional fabrication methods for microstrip antennas, such as photolithography and electron-beam lithography, can be expensive, time-consuming, and may not provide the necessary resolution for terahertz antennas with small features. Therefore, alternative fabrication techniques that offer higher precision and reduced complexity are of great interest in the field.

Additive manufacturing, also referred to as 3D printing technology, has become an essential component in modern 3D fabrication processes, thanks to its rapid prototyping capabilities and cost-effective production, along with the availability of diverse dielectric and conductor materials for use in 3D printing. Among the various additive manufacturing techniques, fused deposition modeling (FDM), digital light processing (DLP), and polymer jetting (PolyJet) are commonly employed for creating millimeter-wave and THz components, such as antennas [29]-[31], waveguides [32]-[33], and THz sensors [34]-[35]. Nonetheless, DLP is often the preferred technique over FDM and PolyJet, given its ability to create high-resolution 3D structures and its wide selection of printable materials [36].

Aerosol Jet Printing (AJP) is an additive manufacturing technique that enables the direct printing of functional materials (droplets of diameter 2 - 5 μm) with high resolution and accuracy, making it suitable for the fabrication of terahertz antennas. The AJP process uses nitrogen gas to atomize ink, and to transport the aerosol mist from the atomizer to a focused nozzle. This technique allows for the fabrication of complex structures with minimal material waste and does not require masks or etching processes, as is the case with traditional methods.

In this paper, we present the design, fabrication, and characterization of a compact microstrip THz antenna with dimensions of 3mm x 2mm, leveraging Optomec's AJP technology for its fabrication. The antenna is designed for operation in a specific terahertz frequency range,

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considering the dielectric properties of the substrate and conductive properties of the printed metallic layer. We first outline the simulation process used to optimize the antenna's performance, followed by a detailed description of the fabrication process using AJP. Subsequently, we present the experimental characterization of the fabricated antenna, including measurements of its radiation pattern, gain, and return loss. Finally, we discuss the implications of our findings and the potential of AJP as a viable and efficient approach for fabricating THz antennas, paving the way for further advancements in terahertz technology and its applications.

II. DESIGN PROCEDURE

A. Simulation Parameters

In this paper, we introduce a 3mm x 2mm microstrip terahertz antenna design, emphasizing the utilization of Ansys HFSS software for simulation purposes. The microstrip lines are printed on a flexible FR4 substrate with a dielectric constant (εr) = 3.55, a material well-suited for terahertz applications due to its low loss properties at higher frequencies. The flexibility of the FR4 substrate expands the potential applications of the antenna, allowing it to adapt to various surfaces and conform to different shapes.

The microstrip antenna design comprises a radiating patch, 2.3 mm x 0.2 mm, and a ground plane, 1.2 mm x 0.2 mm, on the FR4 dielectric substrate. The flexible substrate has a thickness of 0.1 mm. To ensure optimal performance at the desired terahertz frequency, the dimensions of the patch and the microstrip transmission line are meticulously determined. Ansys HFSS, a high-frequency electromagnetic field simulation software, is employed to analyze and optimize the antenna's design parameters, such as resonant frequency, bandwidth, radiation pattern, and impedance matching.

The antenna's operation is based on the excitation of the dominant mode at the target terahertz frequency, with energy radiating from the patch into free space. The ground plane enhances radiation efficiency and minimizes losses. Ansys HFSS simulations enable the assessment of the antenna's performance under various bending conditions, thanks to the flexible FR4 substrate, making it suitable for applications in wearable electronics, flexible communication systems, and conformal radars. Figure 1 shows the simulated THz antenna design.

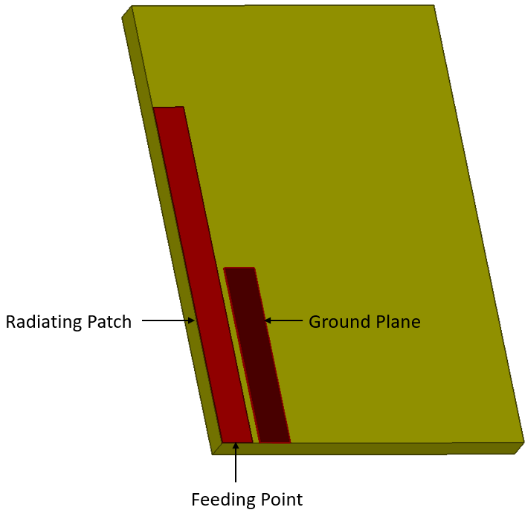

Figure 1. Simulated Design

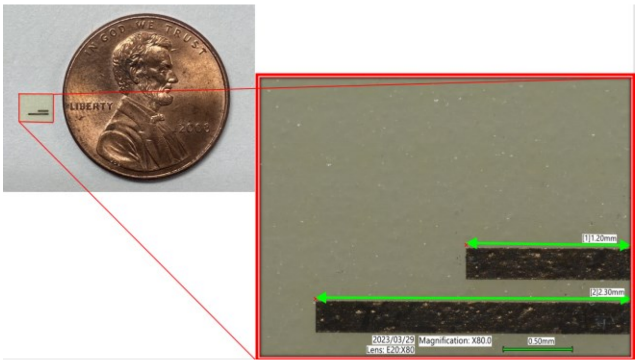

Figure 2. Fabricated antenna next to United States one-cent coin. Magnified image, obtained from high-resolution digital microscope, is shown in red insert.

B. Fabrication Process

For the fabrication of the design, Optomec Aerosol Jet 200 printer was used. This printer has the capability to print fine features, with feature sizes from ~10 to 200 microns. In addition, this printer has achieved print speeds up to 100mm/sec [37]. This machine can effectively print intricate electronic components, such as terahertz antennas, directly onto various heat resistant substrates.

The fabrication process starts with the synthesis of conductive nanoparticle inks, followed by their optimization for optimal viscosity and rheological properties. The Optomec AJP machine then employs a stream of sheath gas in the nozzle to deposit ultrasonically aerosolized ink droplets onto the FR4 flexible substrate surface. By controlling the jetting parameters, such as nitrogen gas pressure and process speed, we ensure uniform and high-resolution deposition of the antenna patterns, leading to improved performance. Post-processing steps, such as sintering and curing, were carried out to achieve high electrical conductivity and adhesion. Figure 2 shows the fabricated THz antenna design next to United States one-cent coin for reference. After processing, the sample is analyzed for defects and fractures using a Keyence VHX-7000 high-resolution digital microscope. The magnified image, including the printed lengths of the radiating patch (2.3mm) and ground plane (1.2mm), obtained from digital microscope is shown in the red insert on the right side of Figure 2. Figure 3 illustrates the Optomec AJP Printer in operation, with a substrate stage, where the flexible substrate is placed for printing, and print head shown in the magnified insert.

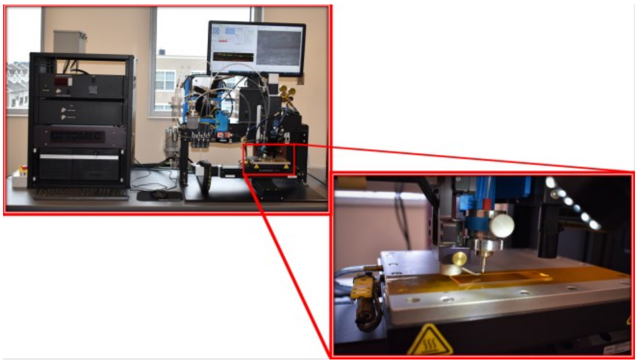

Figure 3. Optomec AJP Printer

III. RESULTS AND DISCUSSION

The simulation results of the proposed antenna are displayed, vis-à-vis, return loss (S_{11}), polar plot of the THz radiation along with a directional 2D radiation plot in H-plane. One of the primary challenges faced by THz antennas is the requirement for suitable calibration mechanisms and electronic components for accurate testing and measurement. This includes ensuring the availability of SMA connectors with proper impedance matching (50 Ohms) within the desired frequency range. Additionally, extended capabilities of the VNA/Anechoic chamber are necessary to validate radiation patterns and S parameters effectively. Currently, we are actively testing the five sets of fabricated antennas, aiming to gather comprehensive measurements across the highest achievable THz frequency range. Upon obtaining and validating the measured results, they will be disseminated in subsequent publications.

Fig 4 and Fig 5 show the simulated S_{11} Plot parameters (between 0.1THz – 0.21THz and 0.1THz – 0.45THz respectively), Fig 6 shows the polar plot, and Fig 7 shows the radiation pattern from Ansys HFSS v2022 software.

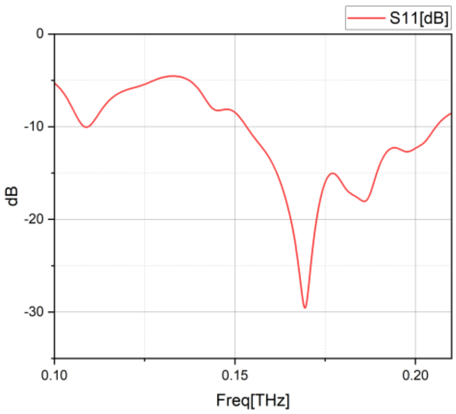

Figure 4. S11 Plot (0.1 – 0.21 THz)

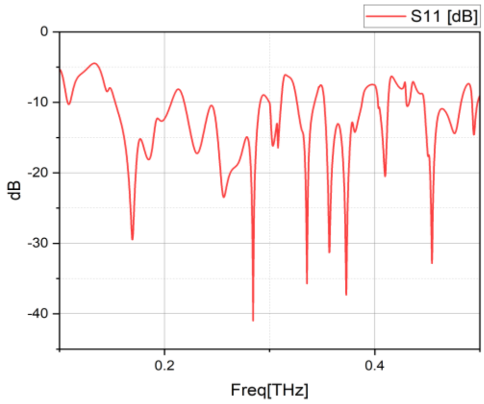

Figure 5. S11 Plot (0.1 – 0.45 THz)

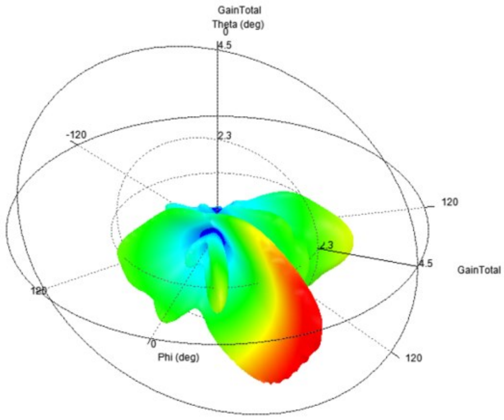

Figure 6. Polar Plot

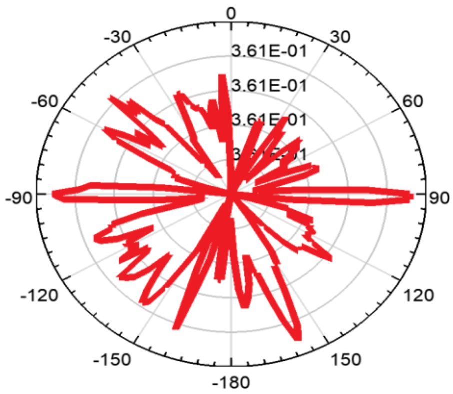

Figure 7. Radiation Pattern

From the simulation results, the antenna shows multi-directional radiation pattern in H-plane at 0.125 THz with a peak gain of 0.38dB. This can be advantageous in certain applications where a more uniform radiation pattern is desired requiring wide coverage such as indoor environments, short-range communication systems, or sensing applications. The multidirectional nature is advantageous for future Many-Input-Many-Output (MIMO) applications owing to selectivity in the directionality. The proposed antenna has impedance bandwidths at 0.1535THz to 0.206THz, 0.2175THz to 0.2903THz, 0.326THz to 0.3427THz, and 0.352THz to 0.388 THz.

IV. CONCLUSION

In conclusion, this paper has presented a novel Terahertz antenna design with promising simulation results, exhibiting multi-directional radiation patterns in the H-plane at 0.125 THz and a peak gain of 0.38dB. The proposed antenna's multi-directional behavior offers significant potential for future Many-Input-Many-Output (MIMO) applications, enabling enhanced directionality and selectivity. Additionally, the antenna showcases wide impedance bandwidths at 0.1535THz to 0.206THz, 0.2175THz to 0.2903THz, 0.326THz to 0.3427THz, and 0.352THz to 0.388 THz, making it suitable for a variety of Terahertz communication systems. However, the primary challenge remains the availability of calibration mechanisms and electronic components for testing and measurement in the Terahertz range. Currently, the testing of the fabricated antennas is underway. Once the measured results are obtained and meticulously validated, they will be shared through upcoming publications. The proposed Terahertz antenna design, bolstered by the simulation results from Ansys HFSS v2022 software, demonstrates its potential to advance the field of Terahertz communications, paving the way for next-generation wireless technologies and applications.

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