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Flexible Antenna Arrays based on Graphene For High-speed THz Communications

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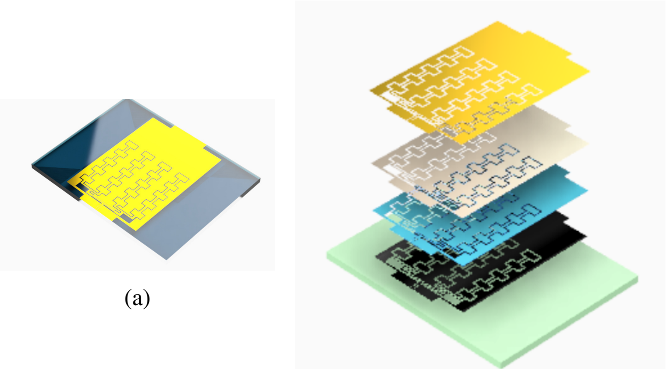
***Abstract*—We present a hybrid antenna design for terahertz (THz) communication. The proposed antenna operates in the frequency range of 0.35-0.45 THz. Simulations show that the combination of graphene material and gold improves the antenna efficiency up to 80% in the desired frequency band. The proposed hybrid design can be used in high-speed wireless communications in the future.**

I. INTRODUCTION

Terahertz (THz) communications offer a terabit per second data rate, which can enable applications not possible with millimetre (mmWave) technologies [1]. THz communications, in comparison to mmWave communications, provide better directionality and security, and are less susceptible to interference and free-space diffraction [2]. This is mostly owing to the shorter wavelengths associated with THz frequencies, which allows for the realisation of THz systems with much lower footprints [3]. For a specific application, millimetre and THz-band communications may significantly improve the reliability and latency of future vehicle networks [4]. Reliable and high-speed communications are important requirements for future vehicular networks, where a vehicle's driver view requires a latency of less than 50 milliseconds and a data throughput of 50 megabits per second [5]. Automatic over-take, on the other hand, needs less than 10 milliseconds of delay in order to be reliable and robust. As a result, experts believe that using the THz spectrum will enhance safety solutions and allow a variety of additional uses [6].

II. ANTENNA DESIGN

The proposed antenna is designed at a scale so that THz fabrication and on-wafer measurement is possible. An ungrounded coplanar waveguide (CPW) was used with 7 μm gap taking into account the THz probe pitch size. Using an ungrounded CPW is one of the solutions to have better impedance matching with a sufficient substrate thickness which can save the sample from being broken during the fabrication process. Between graphene and gold, two different types of metal have been used namely, Titanium (Ti) and Aluminium (Al). Ti and Al have better attachment to the flexible substrate which in this case is polyethylene naphthalate (PEN). Moreover the materials provide low resistance between gold and graphene. The graphene layer to be generated through the chemical vapour decomposition (CVD) is used as a radiation element and gold with 500 nm thickness to meet the THz measurement probe minimum connection thickness. In the proposed antenna array design, the antenna element spacing is set to $\lambda/2$ at 0.4 THz. The resultant design was then optimised using the trust region framework (TSF) algorithm [7] included in CST Studio.


(a)

(b)

Fig. 1: Antenna Arrays Design Structure, (a) Front view. (b) Gold, Aluminium, Titanium, and Graphene

III. RESULT AND DISCUSSION

The antenna was simulated using CST Microwave studio's electromagnetic modelling programme. The suggested antenna's radiation properties were examined in terms of return loss, VSWR, directivity, gain, and radiation pattern in the E- and H-planes.

Total efficiency	70%
Radiation efficiency	80%
Gain	12dBi
Directivity	15dBi
VSWR	1.2

TABLE I: Antenna arrays parameters

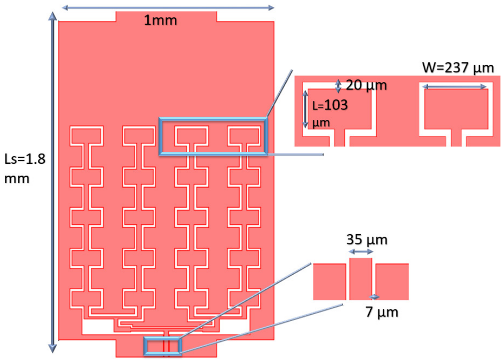


Fig. 2: Cpw THz Antenna Arrays Dimensions

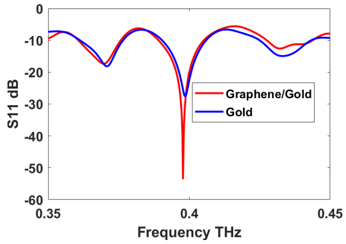
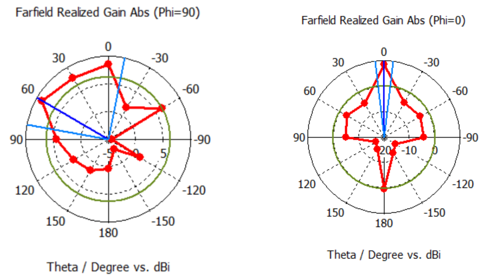
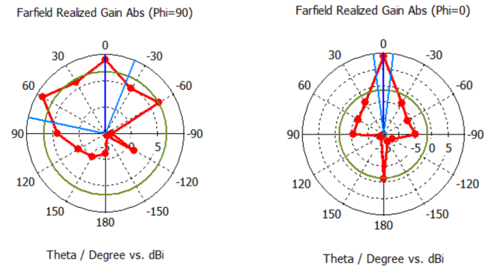


Fig. 3: Simulated reflection coefficient of the antenna array.



(a) 0.39 THz E-plane

(b) 0.39 THz H-plane



(c) 0.4 THz E-plane

(d) 0.4 THz H- plane

Fig. 4: Simulated radiation pattern of the proposed antenna array.

The return loss S_{11} (dB) should be less than or equal to -10 dB for an effective antenna. Figure 3 shows the S_{11} parameter comparison for the gold only and gold with graphene as enhancement material. The simulated reflection coefficient of the 20 elements array shows the excellent antenna performance as the whole response is below the $-10\,\mathrm{dB}$ reflection range. The reflection coefficient was reduced using graphene material with gold compared to a standalone gold antenna array. It has been observed that resonant frequency was shifted slightly towards the higher frequency. The S11 of the gold antenna array scenario is -23 dB at 0.4 THz. The antenna has a wide bandwidth of 29.2GHz. Whereas, the hybrid combination between gold and graphene provides an excellent antenna performance in the desired frequency range 0.4 THz with -55 dB reflection coefficient. Table I breakdown the antenna parameters. The impedance match between the transmission line and the antenna is critical when assessing the performance of the antenna. The voltage standing wave ratio (VSWR) indicates how much signal is reflected back to the source as a result of an impedance mismatch between the source and the antenna. At the complete target frequency range, the VSWR is less than 1.5. The gain of the antenna is maintained above 12 dBi. However, the gain could be lower as compared to antenna design at microwave frequencies where the radiating element acts nearly as a perfect electric conductor. Here however adding graphene has improved the performance. Further investigations in which a substrate with a lower dielectric constant is used improve the radiation efficiency of the designed antenna. Different substrate materials like silicon with high dielectric constant will degrade the radiation of the antenna and absorb some the radiation. Other performance parameters such as the antenna directivity and radiation efficiency are shown in Table.I, which indicates a high radiation efficiency of 80%. The co-polar and cross-polar radiation pattern in both E-plane $(\phi = 0^\circ)$ and H-plane $(\phi = 90^\circ)$ of the proposed graphene array is displayed in Fig.4. By adjusting theta, the antenna is oriented such that the bore-sight direction is toward the vertical. (θ) from 0° to 360° for a fixed value of phi (ϕ). The main lobe magnitude is around 10dBi, main lobe direction is 0°, and angular width $(3\text{ dB})146.4^\circ$ has been obtained for E-plane. For the H-plane, the main lobe magnitude, main lobe direction, and sidelobe level are 5.9 dBi, $30^\circ, -8.9$ dB, and 79.4°, respectively, obtained at resonant frequency 0.4 THz.

IV. CONCLUSION

In this paper, a graphene-based 4×5 CWP antenna array operating in the THz range of 0.35-0.45 THz is designed and analysed. Commonly available metals are used with a view to keep the fabrication process cost-effective and simple. Our design achieved a measured -10 dB return loss, impedance bandwidth of 40 GHz at the centre frequency of 0.4 THz. Results also show that other antenna performance characteristics such as radiation efficiency and gain are also high. We anticipate the designs and techniques used in this paper can launch a new research direction for realizing THz frequency ultrawideband antennas for enabling high-speed wireless communications in the future.

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REFERENCES

[1] K.-C. Huang and Z. Wang, “Terahertz terabit wireless communication,” *IEEE Microwave Magazine*, vol. 12, no. 4, pp. 108–116, 2011.

[2] M. J. Fitch and R. Osiander, “Terahertz waves for communications and sensing,” *Johns Hopkins APL technical digest*, vol. 25, no. 4, pp. 348–355, 2004.

[3] D. L. Woolard, R. Brown, M. Pepper, and M. Kemp, “Terahertz frequency sensing and imaging: A time of reckoning future applications?,” *Proceedings of the IEEE*, vol. 93, no. 10, pp. 1722–1743, 2005.

[4] J. Choi, V. Va, N. Gonzalez-Prelcic, R. Daniels, C. R. Bhat, and R. W. Heath, “Millimeter-wave vehicular communication to support massive automotive sensing,” *IEEE Communications Magazine*, vol. 54, no. 12, pp. 160–167, 2016.

[5] S. Mumtaz, J. M. Jornet, J. Aulin, W. H. Gerstacker, X. Dong, and B. Ai, “Terahertz communication for vehicular networks,” *IEEE Transactions on Vehicular Technology*, vol. 66, no. 7, 2017.

[6] R. Köhler, A. Tredicucci, F. Beltram, H. E. Beere, E. H. Linfield, A. G. Davies, D. A. Ritchie, R. C. Iotti, and F. Rossi, “Terahertz semiconductor-heterostructure laser,” *Nature*, vol. 417, no. 6885, pp. 156–159, 2002.

[7] A. R. Conn, N. I. M. Gould, and P. L. Toint, *Trust-region methods*. MPS-SIAM series on optimization, Philadelphia, PA: Society for Industrial and Applied Mathematics, 2000.