Study on Improvement of the Performance Parameters of a Novel 0.41-0.47 THz On-Chip Antenna Based on Metasurface Concept Realized on 50μm GaAs-Layer

Mohammad Alibakhshikenari[1]*, Naser Ojaroudi Parchin[2], Bal S. Virdee[3], Mohsen Khalily[4], Chan H. See[5,6], Raed Abd-Alhameed[2], Francisco Falcone[7], Ernesto Limiti[1]

[1] Electronic Engineering Department, University of Rome "Tor Vergata", Via del Politecnico 1, 00133, Rome, ITALY
[2] School of Electrical Engineering & Computer Science, University of Bradford, UK
[3] London Metropolitan University, Center for Communications Technology, London N7 8DB, UK
[4] 5G innovation Center (5GIC), University of Surrey, Guildford, GU2 7XH, U.K
[5] School of Engineering, University of Bolton, Deane Road, Bolton, BL3 5AB, UK
[6] School of Eng. & the Built Environment, Edinburgh Napier University, 10 Colinton Rd., Edinburgh, EH10 5DT, UK
[7] Electrical and Electronic Engineering Department, Public University of Navarre, 31006 Pamplona, SPAIN
{alibakhshikenari, limiti}@ing.uniroma2.it, n.ojaroudiparchin@bradford.ac.uk, b.virdee@londonmet.ac.uk, m.khalily@surrey.ac.uk, c.see@bolton.ac.uk, r.a.a.abd@bradford.ac.uk, francisco.falcone@unavarra.es

***Abstract*: A feasibility study is presented on the performance parameters of a novel on-chip antenna based on metasurface technology at terahertz band. Metasurface on-chip antenna is constructed on an electrically thin high-permittivity GaAs layer. Metasurface is created by engraving tapered slots on 11×11 array of circular patches fabricated on the top GaAs layer with metallic via holes that connecting the circular patches to the open-ended feeding slot-lines underneath of the structure. The antenna is coupled electromagnetic to the feed-line. The feed mechanism employed results in wideband performance across 410 GHz to 470 GHz. Radiation performance of the antenna are shown to significantly improve with the metasurface, in particular, the gain increases to 11.9 dBi and radiation efficiency goes up to 81.95%. Dimensions of the antenna are 8.6×8.6×0.053 mm^3.**

***Keywords*: 0.41-0.47 THz on-chip antenna, metasurface concept, gain improvement, wide bandwidth, leaky-wave open-ended slot-lines, gallium arsenide (GaAs) layer, electromagnetic coupling, terahertz (THz).**

I. Introduction

The terahertz (THz) frequency band, which spans the frequencies between 0.1 and 10 THz, offers potential applications in in various disciplines including medical science [1], imaging [2], defence and security [3], time-domain spectroscopy [4], astronomy [5], agriculture [6] and wireless communication systems [7]. Planar Fabry-Perot cavity antennas have been investigated at THz band as they are highly directive and their design and fabrication is of complexity [8, 9]. Unfortunately, the radiation efficiency of these antennas is low especially when implemented on high permittivity substrates [10]. At THz frequencies electrically thick substrates establish unwanted subtrate resonance, however this can be avoided by simply reducing the substrate thickness by $\lambda_o/20$, where λ_o is a free-space wavelength [11].

Metasurface is essentially created by distributing electrically small scattering artefacts over the surface of a dielectric medium in order manipulate propagating electromagnetic waves [12]. In fact, the geometrical shape of the scattering artefacts determine the electromagnetic properties of the metamaterial [13]. Metasurfaces have been shown to enhance antenna performance in terms of gain, radiation pattern, and bandwidth from microwave to terahertz band [14, 15–20]. Results of these investigations reveal that the need for wide-gain-bandwidth antennas that can operate at THz frequencies.

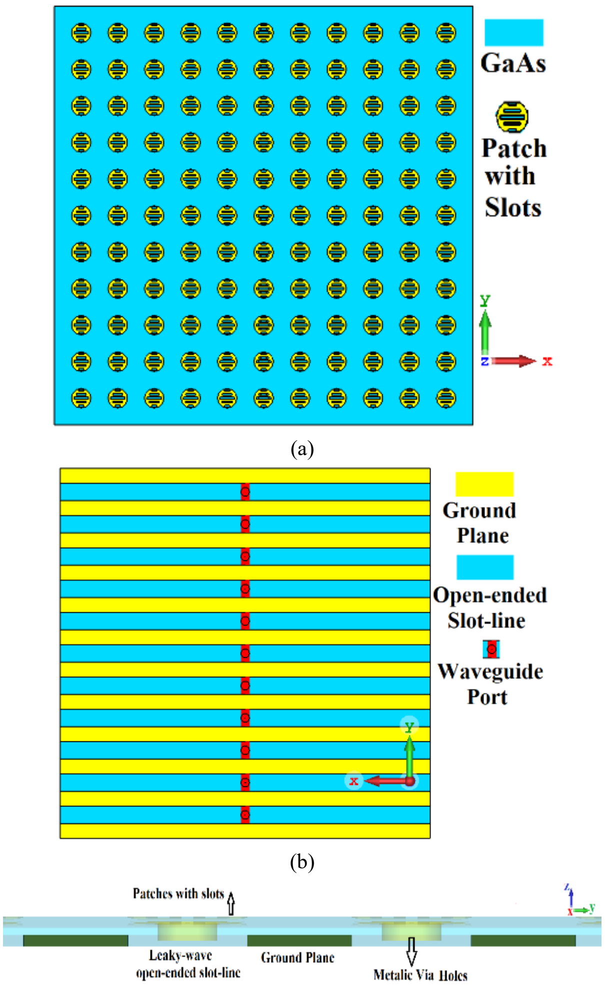
THz signals experience much greater attenuation and atmospheric losses than the conventional microwave links. Hence, antennas with high-gain characteristics essential at the terahertz band. This paper presents a feasibility study of a novel THz on-chip antenna in an attempt to improve its bandwidth, radiation gain and efficiency characteristics. A new feeding mechanism is employed based on metasurface technology. The on-chip antenna consists of a metasurface and a planar open-ended feeding structure patterned on both sides of an electrically thin, high-permittivity GaAs layer. The metasurface, which is realized on the top side of the substrate, consists of a periodic array of tapered slots printed on circular patches. The planar feed structure, which is printed on the bottom side of the substrate, is a wideband, leaky-wave, open-ended slot-line. The antenna is optimized for a maximum bandwidth, high radiation gain and efficiency performance.

II. Metasurface On-Chip Antenna Design Process

Geometry of the proposed metasurface on-chip antenna is shown in Fig.1. The on-chip antenna is patterned on both sides of the GaAs substrate with a dielectric constant of ε_r=12.9, loss-tangent of tanδ=0.006 and thickness of h=50μm (~λ_o/20, where λ_o is the free-space wavelength centered at 0.44 THz). The metasurface is realized on 11×11 array with metallic circular patches including etched tapered slots that are patterned on the top side of the substrate. The circular patch arrays have a periodicity and patch diameter of 0.2 and 0.2, respectively. The slots play the role of the capacitances in the metasurface [21]. The feeding structure, which is an open-ended, leaky-wave, narrow slot-line, has patterned on the bottom side of the substrate. Each open-ended slot-line is punctuated with a metallic via hole at its center, which act as an inductance in the metasurface [22], and connects the top of the structure to its bottom. For modelling purpose each via is connected to a waveguide port.

When the waveguide ports are excited electromagnetic energy flows over the open-ended slot-lines and coupled to the circular patches. The leaked signal from the metasurface slots is radiated. Conductive layer used in the ground-plane with the slot-line feed and the metasurface is Aluminium with a thickness of 0.35 μm and a conductivity of 3.56×10^{7} S/m. The antenna has overall dimensions of $8.6\times8.6\times0.053$ mm^3.

Key design parameters were optimized to achieve the best bandwidth, radiation gain, and efficiency. Dimensions of the optimized parameters, i.e. number of patches, periodicity and patch diameter, diameter of via holes, gap between the via holes, slot width, length and width of the leaky-wave open-ended slot-line, are: 11 mm, 0.2 mm & 0.2 mm, 0.1 mm, 0.4 mm, 0.04 mm, 8.6 mm & 0.4mm, respectively.



(a)

(b)

(c)

Fig.1. Layout of the metasurface on-chip antenna.

The gap between the outermost circular patches and the substrate edge is important. The gap should approximately equal to the distance between two adjacent patches to avoid destructive interference in the lateral and diffracted waves from the substrate edge. This condition is satisfied with the antenna's length of 8.6 mm in the 11×11 element array.

The gain, efficiency and bandwidth of the metasurface on-chip antenna are affected by the reflectivity of the metasurface, which is primarily determined by the geometry and dimensions of the metasurface. If the patch and slot sizes change, the antenna characteristics change because of the variations in resonant frequency. Thus, re-optimization is necessary to achieve the optimum characteristics. Patch periodicity can also significantly impact the antenna's characteristics in terms of gain, efficiency, and bandwidth.

Antenna gain characteristics as a function of frequency were investigated for the different patch array elements. It was discovered that for every configuration of a given patch number the antenna characteristics altered. Hence, this required re-optimization of the antenna. As expected the antenna gain is a function of the patch number but it plateaued after a certain patch number.

III. Metasurface on-Chip Antenna Performance

The optimum performance by the 11×11 patch array in terms of bandwidth, gain and radiation efficiency are shown in Figs. 2 and 3. The on-chip antenna has a wide bandwidth of more than 13.63% (0.41–0.47 THz), which is the main attractive feature of this antenna. The antenna exhibits wideband and stable gain characteristics with a minimum and optimum gain of 9.65 dBi at 0.41 GHz and 11.9 dBi at ~0.45 THz. The corresponding minimum and optimum radiation efficiency are 69.32% and 81.95%, respectively. To evaluate radiation stability, the average radiation gain and efficiency were 11.1dBi and 75.15%, respectively, in the frequency range 0.41-0.47 THz.

Fig.4 shows the radiation patterns of the metasurface on-chip antenna at 410, 450, and 470 GHz. What is observed is a clean radiation patterns with low side-lobe levels and back radiation in both the E- and H-planes at 410, 450, and 470 GHz. The antenna produced directive radiation patterns in H-plane and a wider beamwidth in the E-plane at the specified spot frequencies. Notably, the strong currents flow across the open-ended slot-lines (*x*-direction) producing strong fields in the perpendicular direction that result in a wider beamwidth in the E-plane. The sidelobe levels in both principal planes were very small within the operating bandwidth. More importantly, the antenna showed very low back radiation, resulting in a high front-to-back ratio. Because the radiation pattern of the conventional slot is bi-directional, a back reflector is often used to prevent this situation. However, in the proposed design, a back reflector is unnecessary because of the metasurface with the leaky-wave slot feed opened to free-space, which yield low back radiation.

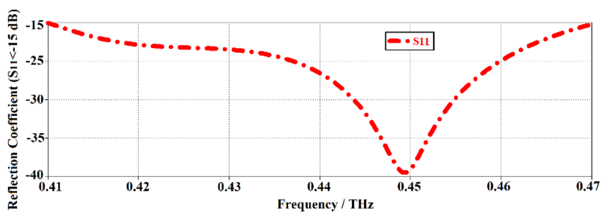


Fig.2. Reflection coefficient (S_{11}<-15dB) of the proposed metasurface on-chip antenna.

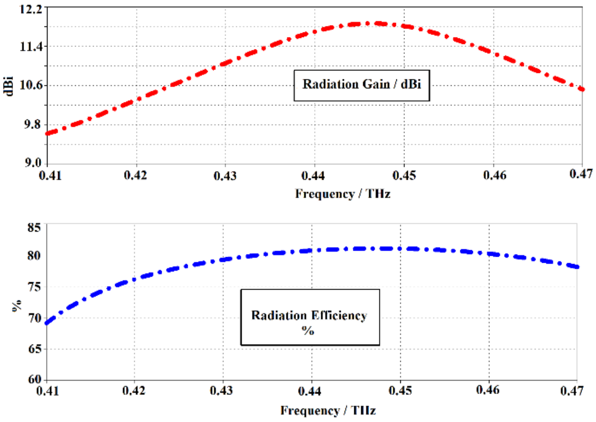


Fig.3. 2-D gain and efficiency plots versus frequency.

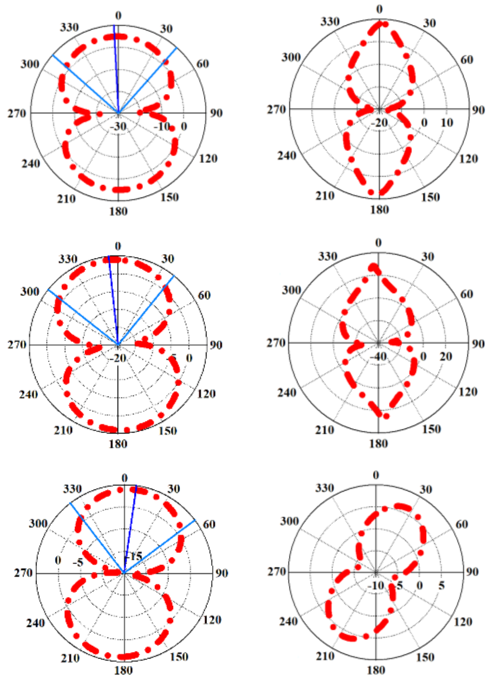


Fig.4. E- and H-planes radiation patterns of the proposed structure at the operating frequencies of 410, 450, and 470 GHz.

IV. Conclusion

The study undertaken demonstrates the feasibility of on-chip 11×11 array antenna at terahertz band. The antenna design is based on a metasurface which is fabricated on a thin but high-permittivity GaAs layer. The metasurface and an open-ended feed structure are fabricated on both sides of the GaAs layer. The antenna provides a gain of 11.9 dBi and radiates with an efficiency of 81.95%.

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