Ceramic material-based optical antenna for multiband photonics applications

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Abstract. The design and development of a multiband ceramic material-based optical antenna are discussed. A square-shaped aperture is utilized to excite the silicon-based dielectric resonator. This type of excitation system provides the capability to create a triple hybrid mode (HEM$^{1\delta,1}$, HEM$^{12\delta,1}$, and HEM$^{1\delta+2,1}$) inside the cylindrical-shaped ceramic material. Due to this feature, the proposed aerial is operating over diverse frequency bands, i.e., 117.5 to 140 THz, 158 to 165.5 THz, and 175.2 to 190.5 THz, respectively. Stable radiation characteristics as well as the good value of gain (about 4.0 dBi) make the proposed nanoradiator applicable for hyperspectral imaging system (125 THz) and VLC for wireless LAN (160/180 THz).

Keywords: optical antenna; multiresonance; hybrid mode; broadsided radiation pattern.

1 Introduction

The design and study of antennas in the optical domain have been a major advancement in nanotechnology in recent years. Optical antennas are widely utilized in imaging, biosensors, optical transmitters, and optical receivers.1–3 It is also used as a feeding technique for waveguide and transmission lines at optical spectrum.4–6 Optical antenna, in general, is a downscaled version of radiators in the RF domain. But the design procedure is not as easy as said. As the frequency of operations moves from GHz to THz, a slew of new difficulties emerge, including high metallic losses due to skin effect, high surface wave losses, and soon, high surface wave losses.7 The use of dielectric resonator-based radiators is the easiest remedy to all these problems. It is due to the natural potential of ceramic-based radiators such as the absence of metallic losses, able to create multiple mode patterns, absence of surface wave losses, and ease to achieve wider impedance bandwidth.8

The literature on antenna design at the optical spectrum is not very mature. A very less number of research articles is present in the open literature. Diverse types of aerials have been structured by researchers at optical spectrum, such as dipole radiator,9 Yagi-Uda radiator,10 graphene-based radiators,11 and aperture antennas.12 However, ceramic-based antennas are widely used at THz frequencies because of their inherent potential.8 In 2013, Zou et al. proposed a dielectric resonator-based array at 633 nm. It supports a single-frequency band and operates at the fundamental mode, i.e., HEM$^{1\delta,1}$. It also supports the broadsided radiation pattern.13 In the same year, Silveira et al. presented stripline-fed ceramic for nanophotonics uses. It is also a single-band antenna and operated at 193.5 THz with broadsided far-field pattern.14 Sethi et al. proposed a microstrip line fed equilateral triangle-based ceramic antenna at 195 THz.
It is designed for the C-band of the optical spectrum. The same research group has again designed as hexagonal shaped DR for 1550 nm optical communication. It operates on HEM$_{20\delta}$ mode and produces an end-fire radiation pattern. Varshney et al. proposed a ceramic-based CP radiator. In the aforementioned antenna structure, the cylindrical-shaped ceramic material is excited by a microstrip line and operated at 195 THz. Low-cost, high gain (THz) DRA is proposed with an on-chip feeding patch for 0.18 μm CMOS technology. Graphene plasmonic dipole is used to excite the DRA and support TE$_{112}$ mode at 2.4 THz. A silicon-made DR is loaded with a graphene nanodisk for achieving tunability in frequency response. CP response of DR is achieved by keeping the rectangular slab at 45 deg for generating orthogonal modes. Gotra et al. proposed single-band circularly polarized graphene-coated DR-based antenna at THz frequency spectrum. CP waves are achieved by placing the graphene coating in orthogonal fashion. Yaduvanshi et al. proposed canonical DRA excited with silver nanostrip. This antenna supports dual-frequency band. In this paper, ceramic material-based nanoantenna is proposed. It is the first time when authors are proposed for multiband application in the optical spectrum. In this antenna design, a square-shaped slot is utilized to excite the nanocylindrical-shaped ceramic material. Because of such type of feed design, three hybrid mode patterns are excited inside the cylindrical ceramic, i.e., HEM$_{115}$, HEM$_{126}$, and HEM$_{116+2}$. This aerial structure supports three diverse frequency bands, i.e., 117.5 to 140 THz, 158 to 165.5 THz, and 175.2 to 190.5 THz, respectively. For a proper understanding of the working of the proposed radiator, this paper is divided into subsections: (i) antenna layout, (ii) its detail analysis, (iii) final outcomes, and (iv) conclusion.

2 Structural Layout of Proposed Nanoantenna

Figure 1 displays the structural layout of the proposed aperture coupled ceramic-based nanoantenna. In this antenna design, cylindrical-shaped silicon material is used as a ceramic. Its permittivity ($\varepsilon_{\text{r, Si}}$) is 11.56. The diameter ($D$) and height ($H$) of cylindrical shaped silicon

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**Fig. 1** Ceramic-based nanoantenna: (a) top view, (b) side view, and (c) 3D view.
material are 1.02 and 0.325 μm. It is located over the SiO₂ substrate with the permittivity (ε_r) of 2.1. The cross-sectional area of the substrate is 4 × 4 μm². The Nanometallic strip line at the bottom of the substrate is made up of silver material. Similarly, a square-shaped aperture has also been etched from the silver-based metallic strip over the upper part of the substrate. Lower silver strip acts as microstrip line, whereas upper silver strip behaves as a ground plane. Size of ground plane is taken as smaller in comparison to substrate because smaller ground size provides better impedance matching as well as reduce scattering at the edges of ground. However, gold has better conductivity and less oxidization rate as compared to silver. But silver is cost-effective and for indoor application, it does not have instant oxidation. So silver is the most suitable material for the proposed antenna. Dispersive kinds of stuff of silver material used in the proposed antenna design have been decided by Drude’s model. It is simply a mathematical model and given as follows:

\[
\varepsilon_{Ag} = \varepsilon_0 \left[ \varepsilon_\infty - \frac{f_p^2}{f + i\gamma} \right].
\]  

In Eq. (1), \( \varepsilon_\infty \) (real part of dielectric constant) = 5; \( f_p \) (plasma frequency) = 2175 THz; and \( \gamma/\pi = 4.35 \) THz. \( \varepsilon_{Ag} \) and \( \gamma \) are the dielectric constant of silver and collision frequency, respectively. \( f \) and \( \varepsilon_0 \) is the operating frequency and permittivity of free space. In Fig. 1, \( h_1 = 0.145 \) μm, \( h_2 = 0.020 \) μm, and \( h_3 = 0.010 \) μm are the depth of the substrate on which the silver strip was placed, height of the silver strip and gap between silicon-based ceramic, and silver strip, respectively. The width of nanosilver-based strip line \( w = 0.340 \) μm with an effective reflective index of about 1.66. All these dimensions are taken from Ref. 14. The width (\( W_A \)) and length (\( L_A \)) of the upper silver strip is 2.0 and 2.5 μm, respectively. Edges of square aperture (\( L_{SA} = W_{SA} \)) have dimension 0.5 μm. In proposed antenna, cylindrical ceramic is not directly contacted with aperture. A dielectric layer is placed in between ceramic and silver strip in order to make it proximity coupling feed mechanism. This type of feeding structure better impedance matching, which can compensate the fabrication tolerances.  

### 3 Detailed Analysis of Proposed Nanoradiator

In this section, theoretical in addition to the mathematical investigation has been carried out with the help of the Ansys HFSS EM simulator. In the proposed antenna design, two different resonating assemblies have been utilized: (i) aperture and (ii) silicon-based dielectric resonator. To confirm the responsibility of resonant peaks produced in the optical spectrum, Fig. 2 displays the \( |S_{11}| \) variation with and without a silicon-based ceramic material. From Fig. 2, it can be observed that all three resonant peaks are due to the silicon ceramic material.

To understand the design methodology, the proposed nanoantenna is designed with the assistance of three steps: (i) silicon ceramic excited with rectangular slot extended toward Y axis; (ii) silicon ceramic excited with rectangular aperture (slot) extended toward X axis; and (iii) square aperture coupled silicon ceramic. Figure 3 shows changes in \(|S_{11}|\) for silicon ceramic material.
excited with rectangular slot extended towards $Y$ axis with change in $L_{SA}$. From Fig. 3, it is established that excitation with the help of a $Y$ oriented rectangular aperture is accountable to produce two diverse modes in silicon ceramic at 125 and 184 THz, respectively. For recognizing the mode, Fig. 4 presents the vectored E-field orientation on silicon ceramic at 125 and 184 THz, respectively. From Fig. 4, it can be said that $HEM_{11\delta}$ and $HEM_{11\delta+2}$ modes are obtained at 125 and 184 THz, respectively.\textsuperscript{25,26} The resonant peak due to $HEM_{11\delta}$ the mode can also be confirmed mathematically using the succeeding formulation:\textsuperscript{27}

$$f_{r,HEM_{11\delta}} = \frac{6.324c}{2\pi D} \sqrt{\varepsilon_{r,\text{Si}} + 2} \left\{ 0.27 + 0.36 \left( \frac{D}{2H} \right) + 0.02 \left( \frac{D}{2H} \right)^2 \right\},$$

(2)

where $D$ and $H$ represent the diameter and height of the dielectric resonator, respectively.

**Fig. 3** Variation in $|S_{11}|$ for silicon ceramic excited with rectangular slot extended towards $Y$ axis with change in $L_{SA}$.

**Fig. 4** E-field variation on Si-based ceramic: (a) upper view at 125 THz, (b) adjacent view at 125 THz, (c) upper view at 184 THz, and (d) adjacent view at 184 THz.
On the other hand, the resonant peak of HEM$_{11\delta+2}$ mode can be projected mathematically as follows:28

\[ f_{r,\text{HEM}_{11\delta+2}} = 1.5 \times f_{r,\text{HEM}_{11\delta}}. \quad (3) \]

In Eq. (3), the scaling factor is 1.5 because HEM$_{11\delta+2}$ mode is the second higher-order mode of HEM$_{11\delta}$ mode. Cylindrical shapes always follow Bessel functions, so the scaling factor is 1.25, 1.5 for first and second higher-order mode respectively.28 From Eqs. (2) and (3), the resonant frequency of HEM$_{11\delta}$ and HEM$_{11\delta+2}$ mode is found as 124 and 186 THz, respectively.

It is well-known fact that if the feeding structure is act as a magnetic dipole, then only HEM$_{11\delta}$ and its higher-order modes are created within the Si-based cylinder.27 Figure 5 shows electric and magnetic field distribution over the rectangular slot extended toward Y axis at 125 THz. After seeing the field distribution, i.e., electric field is maximum at the middle of aperture, it can be said that aperture supports TE$_{10}$ mode, which behaves as a magnetic dipole.29 This is the theoretical reason behind the formation of HEM$_{11\delta}$ mode. The wide slot, as well as the large height of cylindrical ceramic, provides the appropriate boundary conditions for HEM$_{11\delta+2}$ mode.26 Figure 6 displays the reflection coefficient ($|S_{11}|$) variation for silicon ceramic excited with rectangular slot extended toward X axis with changes $W_{SA}$. From Fig. 6, it is confirmed that silicon ceramic excited with rectangular aperture (slot) extended toward X axis supports only a single-frequency band centred at 160 THz. In order to find out the mode at 160 THz, Fig. 7 displays the vectored E-field orientation over the Si-based ceramic at 160 THz. After seeing Fig. 7, it can be said that HEM$_{12\delta}$ mode is accountable for a resonant peak at 160 THz.25

However, for resonant frequency calculation of HEM$_{12\delta}$ mode, there is no pragmatic technique existing in the literature. But its frequency can be forecast with the aid of $f_{r,\text{HEM}_{11\delta}}$, if the aspect ratio of ceramic material is known.30 For the designed radiator, the aspect ratio ($D/H$) of Si-based ceramic is 1.65. For this value of aspect ratio, the scaling factor is 1.3. Therefore, mathematically, it can be written as follows:30

\[ |S_{11}| \quad \text{for silicon ceramic excited with rectangular aperture (slot) extended towards X axis with changes } W_{SA}. \]
From Eq. (4), the resonant frequency of HEM\textsubscript{12δ} mode is approximately found as 161.2 THz, which is nearer to the software-generated outcome. Theoretically, the excitation method must behave like an electric dipole for creating HEM\textsubscript{12δ} mode inside the Si-based ceramic. Figure 8 displays the electric and magnetic field distribution over the rectangular slot extended toward X axis at 160 THz. From Fig. 8, it is confirmed that the behavior of electric and magnetic fields is swap in comparison to field variation at 125 THz. From Babinet’s principle, this is confirmed that the rectangular aperture extended toward X axis behaves like an electric dipole. Therefore, it generates HEM\textsubscript{12δ} mode in Si-based cylindrical ceramic.

From the aforementioned discussion, it is confirmed that Y- and X-oriented rectangular aperture is accountable for HEM\textsubscript{11δ}/HEM\textsubscript{15+2} and HEM\textsubscript{12δ} mode, respectively. To create all three modes in the same Si-based ceramic, it is important that the feed structure must behave as both electric and magnetic dipole. In order to fulfill this requirement, a rectangular aperture is converted into a square aperture and its \( S_{11} \) variation is displayed in Fig. 9. Two vital comments in Fig. 9 are: (i) square-shaped aperture can create all three mode patterns in Si-based ceramic and (ii) optimum result is obtained at 0.5 μm.

### 4 Optimized Outcomes

In this section, a comparison in terms of reflection coefficient has been done using HFSS and CST. The difference in the simulated reflection coefficient \( |S_{11}| \) by utilizing HFSS and CST is shown in Fig. 10, and the two simulation tools’ findings are very close to each other. Also optimized near and far-field results of the proposed nanoantenna are being deliberated, and Fig. 11 presents the \( |S_{11}| \) and gain variation of the proposed ceramic-based nanoantenna. From Fig. 11, it is confirmed that the proposed aerial can be operated over three different frequency ranges, i.e., 117.5 to 140 THz, 158 to 165.5 THz, and 175.2 to 190.5 THz, respectively. The maximum antenna gain is about 4.0 dBi in all three frequency bands, which is quite large in the perspective.
of THz frequency. It is actually because of the no metallic losses and high-radiation efficiency in the case of ceramic-based antennas. Another important observation from Fig. 10 is that the gain rises as the frequency of operation increases. It is because of the existence of a higher-order mode. Antenna gain is proportional to the square of frequency, i.e., $G \propto f^2$.

![Fig. 9](image1.png)

**Fig. 9** Variation in $|S_{11}|$ for square aperture coupled Si-based ceramic with changes in $(W_{SA} = L_{SA})$.

![Fig. 10](image2.png)

**Fig. 10** Optimized $|S_{11}|$ and gain variation of proposed ceramic-based nanoantenna.

![Fig. 11](image3.png)

**Fig. 11** Optimized $|S_{11}|$ and gain variation of proposed ceramic-based nanoantenna.
Figure 12 shows the far-field pattern of the proposed ceramic-based nanoantenna in two planes, i.e., $XZ$ and $YZ$ plane at 125, 160, and 184 THz, respectively. After seeing the radiation pattern, two important observations are obtained: (i) broadside radiation characteristics confirm the generation of hybrid mode at all three frequency points\(^{27}\) and (ii) cross-polarization level is $\sim 15 \text{ dB}$ less as compare to co-polarization level in both the planes, which confirms the good performance of the proposed nanoantenna. Table 1 compares the performance of the proposed

**Fig. 12** Radiation pattern of proposed nanoantenna: (a) $XZ$ plane at 125 THz, (b) $YZ$ plane at 125 THz, (c) $XZ$ plane at 160 THz, (d) $YZ$ plane at 160 THz, (e) $XZ$ plane at 184 THz, and (f) $YZ$ plane at 184 THz.
nanoantenna with other existing ceramic-based nanoantennas. After seeing Table 1, it can be said that the proposed antenna offers better performance as compared to other existing aerials.

5 Conclusion

In this paper, a ceramic-based nanoantenna has been designed and analyzed. After doing the literature survey, the authors have confirmed that it is the first time when a tri-band antenna is designed for wireless photonics applications. Tri-band characteristics have been achieved by creating three different hybrid radiating modes ($\text{HEM}_{11\delta}$, $\text{HEM}_{12\delta}$, and $\text{HEM}_{11\delta+2}$) inside the Si-based ceramic with the assistance of a square-shaped aperture. The proposed nanoantenna is operating over three frequency bands, i.e., 117.5 to 140 THz, 158 to 165.5 THz, and 175.2 to 190.5 THz, respectively. The gain of proposed THz antenna is about 4.0 dBi. Broadside far-field patterns confirm the generation of hybrid mode in cylindrical ceramic. Stable radiation characteristics of proposed antenna makes it employable for hyperspectral imaging system (125 THz) and VLC for wireless LAN (160/180 THz) at optical spectrum.

6 Future Possibilities

Fabrication and measurement of such type of nanoantennas is one of the future possibilities. Some fabrication methods available in the literature for antennas at nanoscale, i.e., ion beam milling and electron-beam lithography. Built-in circular polarization as well as MIMO feature with multiband characteristics is the another important future aspects. Graphene-coated dielectric resonator antenna provides the tuning facility. So multiband generation in such type of antenna is also another future possibility in the area of THz antenna.

References

1. J. N. Anker et al, “Biosensing with plasmonic nanosensors,” Nat. Mater. 7, 442–453 (2008).
2. P. Biagioni, J.-S. Huang, and B. Hecht, “Nanoantennas for visible and infrared radiation,” Rep. Prog. Phys. 75, 024402 (2012).
3. A. Devilez, B. Stout, and N. Bonod, “Compact metallo-dielectric optical antenna for ultra directional and enhanced radiative emission,” ACS Nano 4, 3390–3396 (2010).
4. J.-S. Huang et al., “Impedance matching and emission properties of nanoantennas in an optical nanocircuit,” Nano Lett. 9, 1897–1902 (2009).
5. J. Wen, S. Romanov, and U. Peschel, “Excitation of plasmonic gap waveguides by nanoantennas,” Opt. Express 17, 5925 (2009).
6. M. Schnell et al., “Nanofocusing of mid-infrared energy with tapered transmission lines,” Nat. Photonics 5, 283–287 (2011).
7. P. Bharadwaj, B. Deutsch, and L. Novotny, “Optical antennas,” Adv. Opt. Photonics 1, 438 (2009).
8. R. K. Mongia, A. Ittipiboon, and M. Cuhaci, “Measurement of radiation efficiency of dielectric resonator antennas,” IEEE Microwave Guid. Wave Lett. 4, 80–82 (1994).
9. L. Tang et al., “Nanometre-scale germanium photodetector enhanced by a near-infrared dipole antenna,” Nat. Photonics 2, 226–229 (2008).
10. T. Kosako, Y. Kadoya, and H. F. Hofmann, “Directional control of light by a nano-optical Yagi-Uda antenna,” Nat. Photonics 4, 312–315 (2010).
11. G. Varshney et al., “A proximity coupled wideband graphene antenna with the generation of higher order TM modes for THz applications,” Opt. Mater. 85, 456–463 (2018).
12. L. Novotny and N. van Hulst, “Antennas for light,” Nat. Photonics 5, 83–90 (2011).
13. L. Zou et al., “Dielectric resonator nanoantennas at visible frequencies,” Opt. Express 21, 1344 (2013).
14. G. N. Malheiro-Silveira, G. S. Wiederhecker, and H. E. Hernández-Figueroa, “Dielectric resonator antenna for applications in nanophotonics,” Opt. Express 21, 1234 (2013).
15. W. T. Sethi, H. Vettikalladi, and H. Fathallah, “Dielectric resonator nanoantenna at optical frequencies,” in Int. Conf. Inf. and Commun. Technol. Res., IEEE, pp 132–135 (2015).
16. W. T. Sethi et al., “Nantenna for standard 1550 nm optical communication systems,” Int. J. Antennas Propag. 2016, 1–9 (2016).
17. G. Varshney et al., “Obtaining the circular polarization in a nano-dielectric resonator antenna for photonics applications,” Semicond. Sci. Technol. 34, 07LT01 (2019).
18. C.-H. Li and T.-Y. Chiu, “340-GHz low-cost and high-gain on-chip higher order mode dielectric resonator antenna for THz applications,” IEEE Trans. Terahertz Sci. Technol. 7, 284–294 (2017).
19. H. S. Ehsan et al., “Terahertz dielectric resonator antenna coupled to graphene plasmonic dipole,” in 12th Eur. Conf. Antennas and Propag., Institution of Engineering and Technology, p. 682 (2018).
20. G. Varshney, “Tunable terahertz dielectric resonator antenna,” Silicon 13, 1907–1915 (2021).
21. R. Gupta, G. Varshney, and R. S. Yaduvanshi, “Tunable terahertz circularly polarized dielectric resonator antenna,” Optik 239, 166800 (2021).
22. S. Gotra, V. S. Pandey, and R. S. Yaduvanshi, “A wideband graphene coated dielectric resonator antenna with circular polarization generation technique for THz applications,” Superlattices Microstruct. 150, 106754 (2021).
23. R. S. Yaduvanshi and Nishtha, “Conical dielectric resonator antenna for terahertz applications,” Frequenz 75, 211–220 (2021).
24. J. Huang, “The finite ground plane effect on the microstrip antenna radiation patterns,” IEEE Trans. Antennas Propag. 31, 649–653 (1983).
25. D. Kajfez, A. W. Glisso, and J. James, “Computed modal field distributions for isolated dielectric resonators,” IEEE Trans. Microwave Theory Tech. 32:1609–1616 (1984).
26. L. Guo, K. W. Leung, and Y. M. Pan, “Compact unidirectional ring dielectric resonator antennas with lateral radiation,” IEEE Trans. Antennas Propag. 63, 5334–5342 (2015).
27. R. K. Mongia and P. Bhartia, “Dielectric resonator antennas—a review and general design relations for resonant frequency and bandwidth,” Int. J. Microwave Millimeter-Wave Comput. Eng. 4, 230–247 (1994).
28. R. Garg et al., Microstrip Antenna Design Handbook, Artech House Publishers, Norwood, MA (2001).
29. C. A. Balanis, *Antenna Theory: Analysis and Design*, 3rd ed., John Wiley & Sons, Inc., New York (2005).

30. A. Sharma et al., “Quad-band quad-sense circularly polarized dielectric resonator antenna for GPS/CNSS/WLAN/WiMAX applications,” *IEEE Antennas Wirel. Propag. Lett.* **19**, 403–407 (2020).

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