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Posted Date: 17 April 2023

doi: 10.20944/preprints202304.0385.v1

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Tunable Wideband Cylindrical Dielectric Resonator Inspired Metasurface Absorber for Medical Sensing Applications

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Abstract: In this article, two elliptical-ovel-shaped cylindrical dielectric resonator based wideband Graphene inspired reconfigurable metasurface absorber is designed on diffused quartz substrate having a relative permittivity of 3.75 and conductivity 2200Kg/m^3 with height of 25µm. This metasurface having gold plated ground in microstrip with 5µm which is essential by calculating skin depth at 2.0THz frequency. Two elliptical ovel shaped patches with Graphene plated having built in potential varies 0-2.5eV and relaxation time 1.0ps at 290^{o}K. By changing the relaxation time of Graphene 0.1ps-0.3ps its resonance frequency also varies i.e., reconfigurable property they provide without adding any active i.e., PIN diode components. The proposed MS is designed having a dimension of 100×100µm^2 is designed on a microstrip. This MS works in the range of 1.6-2.38THz having more than 90% absorbance with two transmission zero at 2.1THz and 2.3THz having high Q > 50 which is used to determine the sensitivity where the proposed MS used as a sensor to determine hemoglobin (Blood Glucose level) and urine (Uric acid) by changing their refractive index from 1.34-1.43. Maximum sensitivity achieved at 2000GHz/RIU and average sensitivity for hemoglobin and urine sensing achieved 833.33GHz/RIU, FOM-8.33 and 4277.7733GHz/RIU, FOM-555.55 respectively.

Keywords: cylindrical dielectric resonator based metasurface-CDRM; wideband- WB; graphene-GR; metasurface-MS; terahertz-THz; EMI-electromagnetic interference; absorbance-ABS; FOM-figure of merit; Q-quality factor; bio-medical sensing

1. Introduction:

The metasurface (MS) is an artificial compound formation assembled periodically with an array of sub-wavelength structural units along with a distinctive response to electromagnetic waves. Metasurfaces possess negative permittivity, permeability, and refractive index as well as an inverse Doppler effect, and inverse Snell's law. Owing ultimate properties and responses, MS holds various applications such as cloaking, absorber, hyper lenses, modulators, holography, etc. Presently, metasurface absorber (MSA) illustrates wide applications in medicine, biology, and aerospace and accomplish high THz wave absorption [1]-[2]. A reconfigurable, flexible, dual band MSA has been proposed [3] for efficient sensing and filtering processes. An all-dielectric resonator metasurface has

 doi:10.20944/preprints202304.0385.v1

been reported [4] to obtain near perfect absorption for THz waves. A hybrid dielectric waveguide resonances based all dielectric MSA with 97.5% of absorption has been reported [5]. Lately, by using self-assembly technique, an all dielectric MSA has been proposed [6] which is based on zirconium dioxide (ZrO2) microspheres. To prevent joule heating dielectric-based resonators provides more temperature stability than metallic based resonators for applications. Even though fabrication of all-dielectric MSAs have low cost with high absorption for THz waves. Graphene attracted significant attention as a 2D material with unique properties, like tremendous thermal and electrical conductivity, optical transparency, flexibility, and great mechanical strength with a zero bandgap. Graphene used with MSs, provided tunable response to EM waves in THz and microwave band by electrochemical potential. Nowadays, graphene-based metasurfaces and associated devices not constrained to tunable absorbers, dynamic beam steering, reconfigurable antennas, and attenuators, besides all enhancing graphene characteristics in the microwave region. Graphene based MS provides stealth, communications, imaging, defense and security systems in infrared, terahertz, and microwave regime. A novel design of a patterned graphene-based plasmon-induced transparency (PIT) metasurface for absorption and slow-light applications in THz communication has been developed in [7]. Represents an ultrathin and broadband reflective cross-polarization converter by using a single-layer THz metasurface contains a couple of modified dumbbell shaped resonators linked with a conductive strip [8]. The broadband and switchable characteristics covers resonant frequencies of 1.98THz, 2.61THz, 2.95THz, and 3.93THz. A Graphene-based metasurface biosensor to sense the hemoglobin biomolecules with great sensitivity has been proposed for secure data communication and sensing applications [9]. Here, a polarization conversion device using hollow graphene based metasurface with efficient outcomes is discovered [10]. Due to excellent performance of proposed device, it is widely applicable for polarization sensor, switches and additional elements for optical polarization control. A small size THz scanning and imaging systems and a new reconfigurable element has been proposed in [11] by suitable automation, the reprogram ability of the graphene-based meta-mirror. The outcomes of the proposed design find near to the diffraction limit with high focusing range and low focusing error. A graphene-based broadband metasurface absorber has been proposed in [12] for the tunable THz frequency range (3.69–9.77THz) with more than 90% absorptivity. Tunability can be achieved using Graphene in the metastructure and the proposed absorber structure is applicable for sensing, spectroscopy, etc. Paper [13] reported a detailed survey of a tri-band graphene-based transmittive-type polarization converter for various applications in THz frequency range like electromagnetic measurement, detection, sensing, imaging, antenna, and stealth technology. A new graphene based metasurface has been designed [14] show in gear-unity absorption within a broad band ranging from 2.06 to 11.80THz. The proposed absorber comprises polarization independent property, stable absorption and useful for numerous applications in THz range like sensors, detectors, spatial light modulators, spectroscopic detectors and for 5G communication system. Article [15] investigated a monolayer graphene-based metasurface for the application of sensing and spectroscopy, acting as a wideband polarization converter. A new technique has been developed [16] to design optical logic gates based on graphene metasurface in terahertz range of frequency. The proposed design permits the logic operation of AND, OR, and XOR by regulating the relative phase difference of input signals. This design is broadly utilized in ultra-compact integrated circuits and ultrafast all-optical signal processing. An infrared biosensor based on graphene metasurface has been proposed [17]. It provides excellent sensitivity (2571nm/RIU) by placing C-shaped tungsten metasurface over graphene material. The proposed biosensor is mostly applicable for medical and photovoltaic devices. To achieve high flexibility, outstanding wave control and good optical transparency, a patterned graphene based metasurface structure has been designed [18] and useful for electromagnetic compatibility, stealth, photovoltaic solar cells, and medical communication. This structure showing high absorption over a wide tunable frequency range. A highly sensitive graphene-based biosensor has been proposed to sense the biomolecules of hemoglobin and urine from a given concentration [19]. The value of absorption depends upon the thickness of different physical layers, the chemical potential of graphene material and the metasurface shape and size. A graphene based metasurface inspired

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highly sensitive refractive index sensor has been proposed [20] for medical and diagnostic applications. Sensing observation for hemoglobin biomolecule concentrations (5000nm/RIU) has been performed by mathematical analysis. The absorption response is obtained by changing the thickness of substrate, ground plane and double split-ring resonator metasurface. A patterned graphene based metasurface absorber with sandwich structure has been presented [21] for EM stealth in microwave band. A graphene based tunable metamaterial absorber has been presented [22] with dual absorption peaks at 10.96THz and 12.71THz for infrared, filter, and terahertz detection. Paper [23] proposed a graphene based dual wideband terahertz metamaterial absorber with dual wide absorption bands (1.4 - 1.9THz and 4.5 - 5.1THz). To sense the biomolecules of hemoglobin and urine a new metasurface plasmonic biosensor based on graphene has been proposed [24]. The proposed biosensor uses gold split-ring resonator for the development of metasurface and it is suitable for medical biosensing devices. The article [25] proposed an ultrathin, polarization-insensitive, wideband tunable, graphene based metasurface absorber at terahertz frequencies (2.24–4.67THz). The reported structure is suitable for stealth technology, security, and satellite communication systems. A new approach is reported [26] for developing Graphene and metallic metasurface based simple dual band absorbers for THz and mid-infrared system applications, respectively. Graphene based structure achieved 98% of absorptivity at 0.53 and 1.53THz and metallic based structure achieved 98% of absorptivity at 7 and 25THz. Paper [27] proposes a THz metasurface absorber with multi-frequency selectivity (absorption 94.50% at 0.366THz, 99.99% at 0.507THz, 95.65% at 0.836THz, 98.80% at 0.996THz, and 86.70% at 1.101THz) and good incident angle compatibility property. It is useful in resonators, bio detection, beam-controlled antennas, hyper-spectral thermal imaging systems, and sensors as shown in Figure 1. An efficient graphene-based C-shape metasurface absorber has been reported [28] for solar energy- harvesting photovoltaic devices and sensors. A dynamic tunable broadband microwave absorber contains layers of wide area graphene and random metasurface has been developed [29] for desired bandwidth from 5 to 31GHz. Article [30] represents a new bilayer all-dielectric polydimethylsiloxane resonator-based structure of a dual-band (at 2.167THz and 2.452THz) metasurface THz absorber.

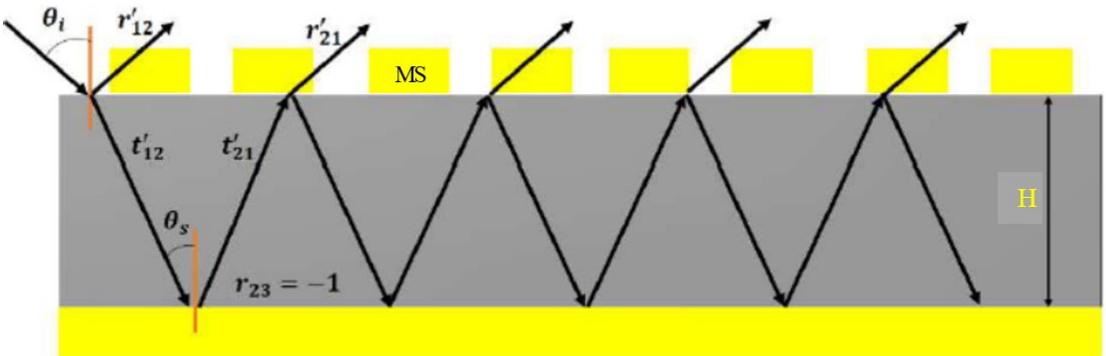

Figure 1. Metasurface (MS) multiple reflection ray model.

In this article, dual oval shaped Graphene inspired tunable metasurface (MS) has been design on a quartz substrate (ε_r = 3.5) with a substrate height of H = 25μm with GaAs based cylindrical resonator having height CDR_H = 45μm for achieved wide bandwidth from 1.6-2.4THz. The proposed MS having good sensitivity for hemoglobin and urine sensing application. All MS designing and analysis are explained in Section-2. In Section-3 MS as a bio sensor and MRI scanning application has been discussed with their sensitivity and Figure of Merit (FOM).MS parametric results discussion and comparison with existing literature explained in Section-4 and conclusion of the article is mentioned in Section-5.

2.1. Designing and Analysis of Proposed Wide Band Metasurface Absorber:

The proposed wideband (1.6-2.4THz) characteristic cylindrical dielectric resonator-based MS is designed on a gold plated (t = 5μm) with Quartz substrate with a dielectric constant 3.5 and height

25μm as depicted in Figure 2a–c. This MS is constructed by 5μm width and 45μm height cylindrical GaAs dielectric (ε_r = 13.1) and Graphene loading MS having to improve the >90% absorbance bandwidth in the range of 1.6-2.4THz. Back side is fully laminated with gold film having conductivity 4.3×10^7S/m to reduce the transmission loss (S_{21} = 0) which improve the absorbance $A(\omega)=1-|S_{11}(\omega)|^2-|S_{21}(\omega)|^2$ for fully laminated MS it reduces to $A(\omega)=1-|S_{11}(\omega)|^2$. Graphene material plays an important role for tunable performance by changing Graphene.

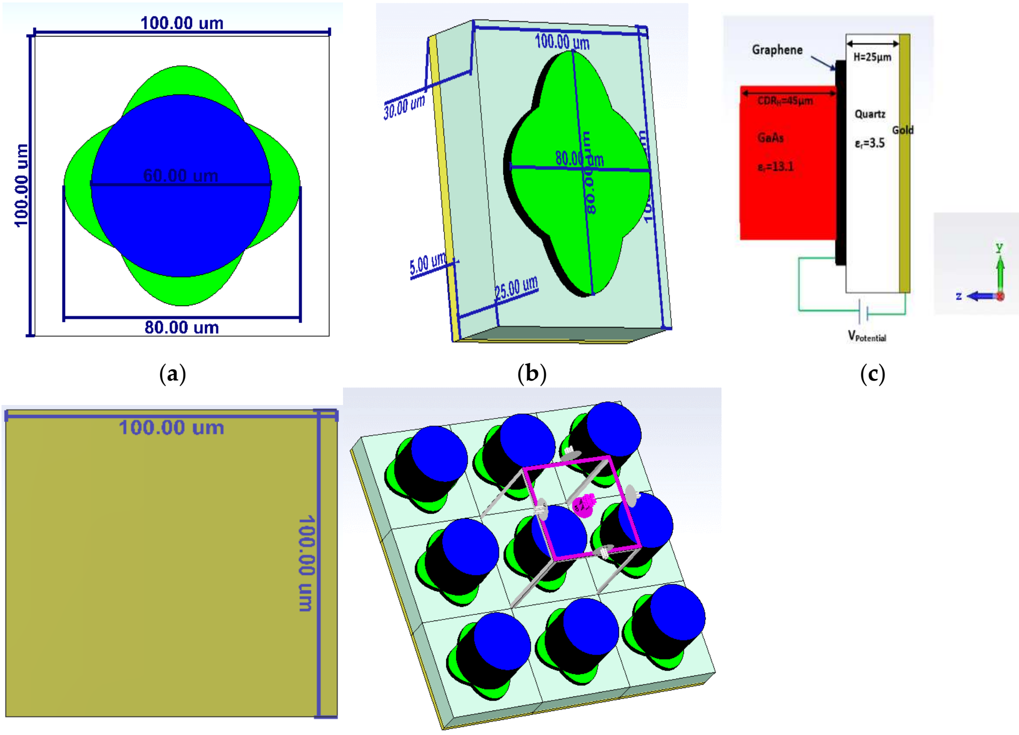

Figure 2. A Graphene based CSRR loaded wideband THz DRA (a) Front view (b) Back view (c) Prospective view.

$$k_x=\frac{\pi}{a}, \text{ and } k_y=\frac{\pi}{b} \tag{1}$$

$$k_z\tan(k_z d/2)=\sqrt{(\varepsilon_r-1)(k_0^2-k_z^2)} \tag{2}$$

$$k_x^2+k_y^2+k_z^2=\varepsilon_r k_0^2 \tag{3}$$

$$k_0=\frac{2\pi f_0}{c} \tag{4}$$

Where k_x, k_y, and k_z are wave numbers along the X, Y and Z axis respectively. Speed of light in air denoted by c and k_0 denotes the free space wave number at resonant frequency f_o (2.0THz). By using matrix laboratory extracted the value of cylindrical DRA (convert rectangular to cylindrical coordinates) which are cylindrical dielectric resonator radius 30μm and height CDR_H = 45μm and azimuth angle (ϕ) = 0^o-360^o for calculation.

2.2. Analysis of Metasurface:

Effective impedance and refractive index of the proposed graphene loaded metasurface can be extracted by Equations (5)–(7) [15].

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$$z=\pm\sqrt{\frac{(1+S_{11})^2-S^2{}_{21}}{(1-S_{11})^2-S^2{}_{21}}} \tag{5}$$

$$e^{jnk_0H}=\frac{S_{21}}{1-S_{11}\frac{z-1}{z+1}} \tag{6}$$

$$n=\frac{1}{k_0H}\left[\left\{\left[\ln e^{jnk_0H}\right]''+2m\pi]\right\}-j[\ln e^{jnk_0H}]'\right] \tag{7}$$

Here, Z and k_0 denotes the impedance of the MS and the wave number. Maximum thickness of dielectric is denoted by H. $\left[\ln e^{jnk_0H}\right]''$ and $[\ln e^{jnk_0H}]'$ are the complex conjugate and real conjugate of a complex number. Permittivity (ε_r) and permeability (μ_r) of the proposed MS can be extracted by refractive index (n) and z shown in Equation (8).

$$\varepsilon_r=\frac{n}{z}\ \ \&\ \ \mu_r=n\times z \tag{8}$$

2.3. Analysis of Metasurface based on Sensitivity (S), Q-factor and Figure of Merit (FOM):

By changing of frequency Δf with respect to change in refractive index Δn is called sensitivity S and it is denoted by Equation (9).

$$S=\frac{\Delta f}{\Delta n} \tag{9}$$

To judge the sensing proficiency of the sensor figure of merit (FOM) is an important parameter.

$$FOM=\frac{S}{FWHM} \tag{10}$$

FOM of any sensor is calculated by Equation (10) where S denotes the sensitivity of the sensor and FWHM provides full width half maximum information. Quality factor-Q also an important parameter to judge the sensor quality for sensing operation its value too high as possible. It is calculated by Equation (11).

$$Q=\frac{f_r}{FWHM} \tag{11}$$

Where f_r represents resonant frequency of the proposed MS absorber.

2.4. Analysis of Graphene Conductivity:

In a Graphene single layer structure Carbon atoms are arranged like a honey comb lattice. Bio sensor is designed by using Graphene material due to its excellent electrical and optical properties.

Thickness of monolayer graphene is considered as 0.29nm for analysis of unit cell metasurface. Summation of Inter-band and intra-band Graphene conductivity (σ_s) is defined by Kubo formula given by Equations (12)–(15).

$$\varepsilon(\omega)=1+\frac{\sigma_S}{\varepsilon_o\omega\Delta} \tag{12}$$

$$\sigma_{Intra}=\frac{-je^2k_bT}{\pi\eta^2(\omega-j2\Gamma)}\left(\frac{\mu_c}{k_bT}+2\ln(e^{\frac{-\mu_0}{k_bT}}+1)\right) \tag{13}$$

$$\sigma_{Inter} = \frac{-je^2}{4\pi h} \ln\left(\frac{2|\mu_c| - (\omega - j2\Gamma)h}{2|\mu_c| + (\omega - j2\Gamma)h}\right) \tag{14}$$

$$\sigma_S = \sigma_{Intra} + \sigma_{Inter} \tag{15}$$

Where Δ denotes the graphene thickness,ω is angular frequency where the MS resonate, ε_0 is the permittivity in vacuum, T is the temperature in Kelvin (K), Γ is scattering rate, μ_c is chemical potential (2.0eV), h, k_b and e are the plank's constant, Boltzmann constant and electron charge value respectively. The chemical potential of graphene varies from 0-2. 5eV. In Figure 3, Graphene surface conductivity high -35dB at lower band of frequency 0.1-20THz and lower at 800THz closed to -135dB.

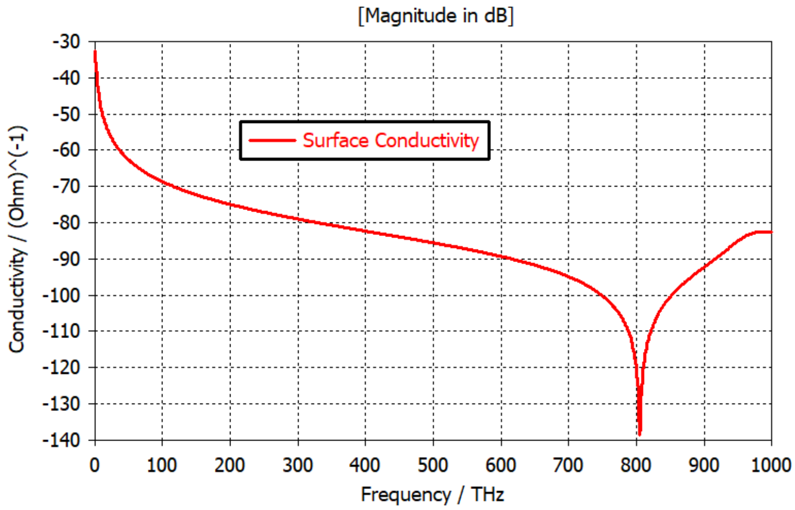


Figure 3. Graphene Conductivity with respect to frequency.

2.5. Analysis of Absorption Reflectance:

The absorption of proposed Graphene-based MS can be obtained by Equations (16)–(22) [15]. This absorption equation can be obtained from graphene conducting equation.

$$r(\omega,\theta_i) = \frac{\omega\cos\theta_i \prod_{00}(\omega,\theta_i)}{2ihck^2 + \omega\cos\theta_i \prod_{00}(\omega,\theta_i)} \tag{16}$$

$$\sigma(\omega,k) = -i\frac{\omega}{4\pi hk^2}\prod_{00}(\omega,k) \tag{17}$$

$$r(\omega,\theta_i) = \frac{2\pi\cos\theta_i\sigma(\omega,k)}{c + 2\pi\cos\theta_i\sigma(\omega,k)} \tag{18}$$

$$R(\omega,\theta_i) = |r(\omega,\theta_i)|^2 \tag{19}$$

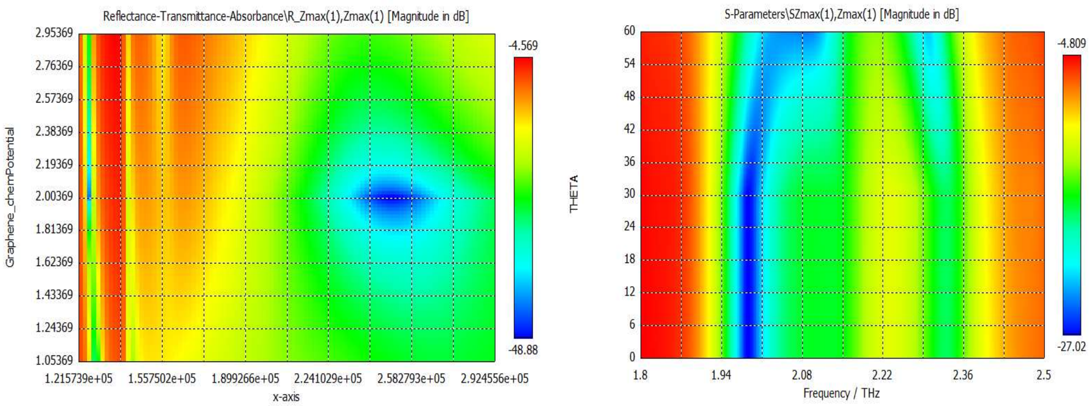
$$R(\omega,\theta_i) = \frac{4\pi^2\cos^2\theta_i\left[\mathrm{Re}^2\sigma(\omega,k) + \mathrm{Im}^2\sigma(\omega,k)\right]}{\left[c + 2\pi\cos\theta_i\,\mathrm{Re}\,\sigma(\omega,k)\right]^2 + 4\pi^2\cos^2\theta_i\,\mathrm{Im}^2\sigma(\omega,k)} \tag{20}$$

$$R(\omega) = R(\omega,0) = \frac{4\pi^2\left[\mathrm{Re}^2\sigma(\omega) + \mathrm{Im}^2\sigma(\omega)\right]}{\left[c + 2\pi\,\mathrm{Re}\,\sigma(\omega)\right]^2 + 4\pi^2\,\mathrm{Im}^2\sigma(\omega)} \tag{21}$$

 doi:10.20944/preprints202304.0385.v1

$$A(\omega) = 1 - R(\omega) - T(\omega) \tag{22}$$

Where θ_i denotes the incident angle having a function of frequency (ω), $\prod_{uv}(\omega, k)$ provides the information about graphene polarization tensor with the value of u, v = 0, 1, 2 and MS bottom layer is fully laminated with gold so that $T(\omega) \approx 0$ and absorption is extracted from Equation (13). In Figure 4a shows the absorbance of the proposed MS by changing of Graphene chemical potential and conclude that if chemical potential increases then then maximum absorbance bandwidth increases.



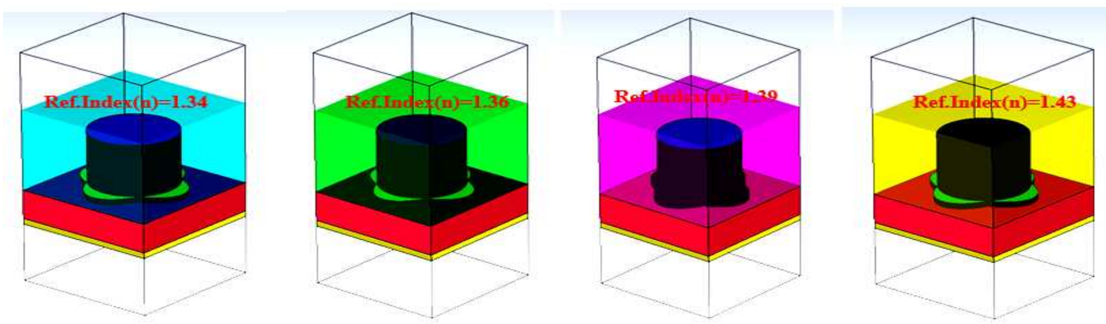
(**a**) (**b**)

Figure 4. Absorbance of the proposed MS (a) By changing Graphene chemical potential (b) By changing θ (Incidence angle).

In Figure 4b, it shows effect of the MS absorbance and reflectance by changing of incidence angle and conclude that it is polarization insensitive in nature w r t incidence angle θ.

3.1. Proposed MS as a Bio-Sensor (Hemoglobin and Urine):

In this section MS as a bio-sensor (hemoglobin and urine) has been discussed. Hemoglobin concentration (g/l) has been correlated with different refractive index (n) = 1.34 to 1.43 shown in Figure 5a,b. In Table 1 proposed MS as a Hemoglobin sensor with refractive index, resonance frequency and sensitivity has been discussed and avg. sensitivity achieved 8333.33GHz/RIU and avg. FOM-8.33.



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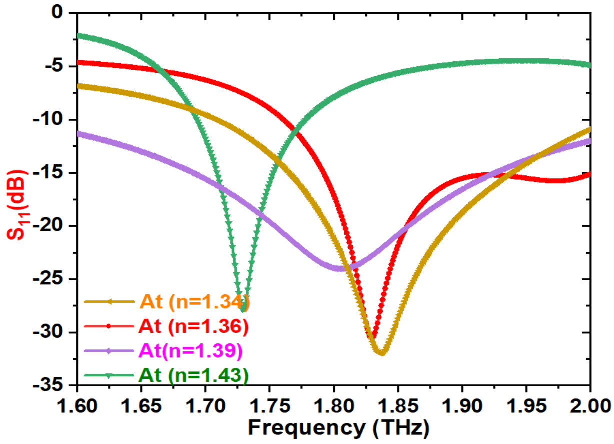

(b)

Figure 5. Proposed MS (a) As a Hemoglobin Bio Sensor (b) S11 at different Refractive Index.

Table 1. Proposed MS as a Hemoglobin sensor with Refractive index, Resonate Frequency and Sensitivity.

S. No.	Concentration (g/l)	Hemoglobin Refractive Index	Resonate Frequency (THz)	Sensitivity (GHz/RIU)	FOM
1.	10	1.34	1.84	500GHz/RIU	5000
2.	20	1.36	1.83	1000GHz/RIU	10000
3.	30	1.39	1.80	2000GHz/RIU	10000
4.	40	1.43	1.72	AVG = 833.33GHz/RIU	AVG = 8333

In Figure 6, the proposed MS as a urine Bio-sensor with different refractive index 1.3326,1.3327,1.3329 and 1.3335 for 10, 20,30 and 40g/l urine concentration shown in Table 2. Sensitivity and FOM for urine sensor are 4277.77GHz/RIU and 555.55 respectively. So, proposed MS having good sensitivity and FOM as a hemoglobin and urine sensor.

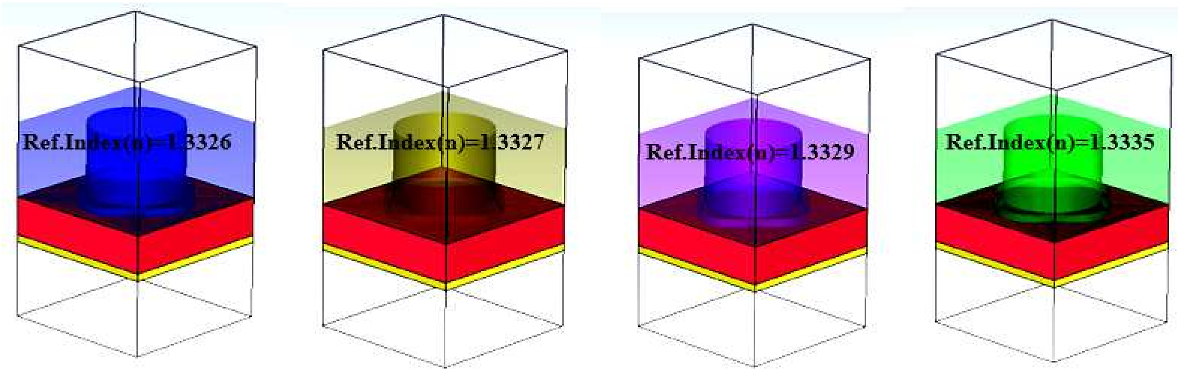

Figure 6. Proposed MS as a urine Bio-Sensor with different refractive index.

Table 2. Proposed MS as a urine sensor with Refractive index, Resonate Frequency and Sensitivity.

S. No.	Concentration (g/l)	Urine Refractive Index	Resonate Frequency (THz)	Sensitivity (GHz/RIU)	FOM
1.	10	1.3326	1.8412	6000GHz/RIU	1000
2.	20	1.3327	1.8406	5000GHz/RIU	500
3.	30	1.3329	1.8396	1833.33GHz/RIU	166.66
4.	40	1.3335	1.8385	AVG = 4277.77GHz/RIU	AVG = 555.55

3.2. Proposed MS in MRI scan and MRI Coil:

The proposed MS used in MRI scanning and MRI coil application are shown in Figure 7a,b where port-1 and port-2 denotes Flaoquet ports in Z_{max} and Z_{min} direction of MS. M_1 and M_2 denotes capacitance associated with MS (plate capacitance, gap capacitance) and L_1 and L_2 denotes inductance associated with MS. So, the proposed MS detect the clouting of blood in MRI scan which is also used as MRI coils.

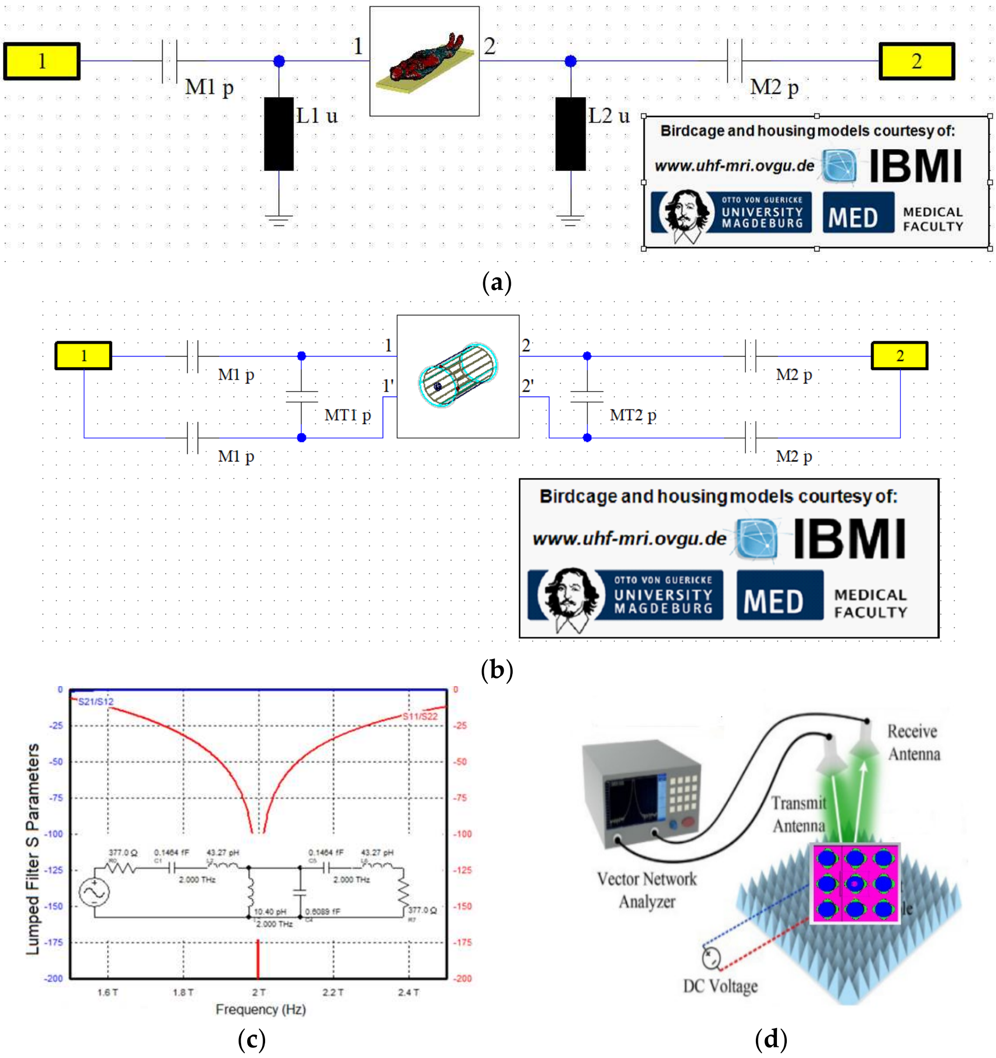

Figure 7. Circuitry model of proposed MS absorber in (a) MRI scan arrangements (b) MRI coils arrangements (c) Proposed MS equivalent electrical model (d) Proposed MS arrangements with VNA in anechoic chamber.

Equivalent parallel LC (patch-dielectric) LC components value for wide band MS absorber are 10.4pH and 0.6089pF and series dielectric-ground LC components values are 43.27pH and 0. 1484pF. Patch-dielectric LC components values are 43.27pH and 0.1484pF and by adding this value its return loss having greater than 10dB in 1.6-2.4THz frequency shown in Figure 7c. In Figure 7d MS arrangements with VNA and Tx and Rx horn antennas are shown to measure the return loss and absorbance. Transmitter and receiver horn antenna is used for wide band application and it supports maximum number of modes supports to this antenna. The proposed MS having polarization insensitiveness from angle of incidence 0-60^o. By changing of Graphene chemical potential tune-ability of MS is possible.

Table 3. Equivalence capacitances and inductances values of the electrical equivalent network of the proposed Graphene inspired Wide band THz Meta surface (MS).

Frequency (THz)	Parallel LC (Patch-dielectric)	Series LC (Dielectric-ground)	Series LC Patch-Dielectric (Si and Graphene)
1.6-2.4	$L_2 = 10.4pH$, $C_2 = 0.6089pF$	$L_1 = 43.27pH$, $C_1 = 0.1484pF$	$L_1 = 43.27pH$, $C_1 = 0.1484pF$

4. Graphene Inspired Tunable THz Absorber Parametric Results:

Graphene with Si dielectric resonator-based MS parametric results shown in Figure 8a–f. Graphene material used for designing a proposed MS patch which shows tunable properties when chemical potential of graphene changes from 0eV-2.5eV shown in Figure 8a.

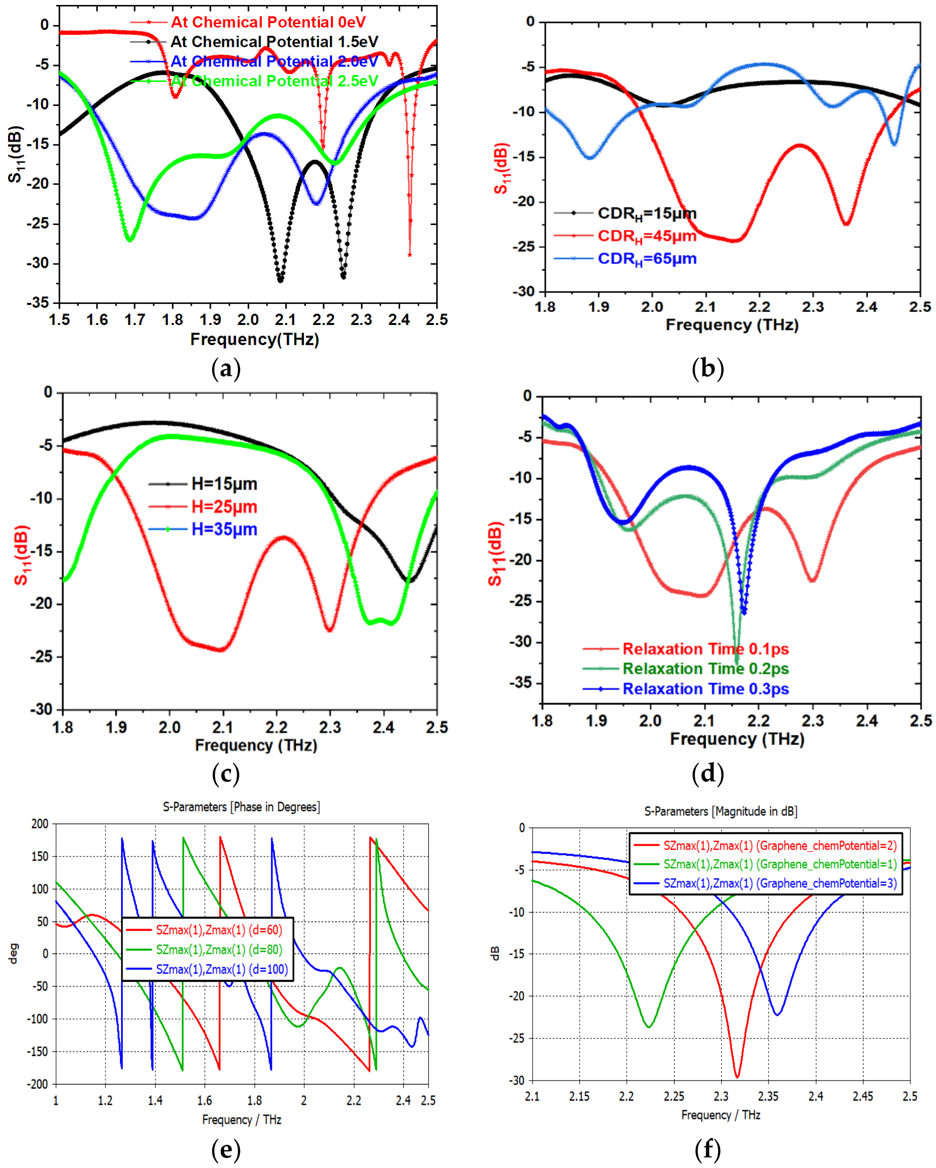

Figure 8. Simulated results of the proposed MS (a) S_{11}-parameter with different graphene chemical potential (b) S_{11}-parameter with different cylindrical dielectric resonator height (CDR_H) (c) S_{11}-parameter with different substrate height(H) (d) S_{11}-parameter with different graphene relaxation time (e) S_{11}-parameter phase at different DRA+substrate height (f) S_{11}-parameter without DRA at different Graphene potential.

At 0eV MS tuned two narrow frequency band at 2.18THz and 2.43THz having S_{11} 15dB and 27.5dB respectively. At 1.5eV, 2.0eV and 2.5eV chemical potential multiband tuned with wide band characteristics from 1.95THz-2.35THz, 1.6THz-2.38THz and 1.6THz-2.4THz respectively. In Figure 8b effect of dielectric resonator height (CDR_H) on return loss shows and conclude that CDR_H=45μm is provide best results to ensure the >90% absorbance in resonating bandwidth. Change of dielectric height (H) effect on S_{11} shown in Figure 8c and confirm the H = 25 μm getting best S_{11} results. Relaxation time also plays an important role to fix the specification of good MS absorber. At relaxation time 0.1ps it gives best results which is suitable for >90% absorbance/ S_{11}>10dB in resonating bandwidth shown in Figure 8d. S_{11} phase with respect to frequency shown in Figure 8e which shows metasurface properties where in that frequency range its value changes from $+90^0$ to -90^0. Without cylindrical dielectric resonator with different graphene chemical potential S_{11} parameter has been discussed in Figure 8f and see that if chemical potential increases then resonance frequency shifted to higher side i.e. at 1eV, 2eV and 3eV its resonate frequency 2.23THz, 2.32THz and 2.36THz which shows the tunability without using any active components like PIN diodes.

Table 4. Comparison table of proposed MS with existing Literature.

Ref.	Modified Technique Resonator	Frequency (THz)	Thickness (μm)	Stability in Degree	Material	Sensitivity (GHz/RIU)
[8]	Modified dumbbell pair	0.4-0.6	75	40	Silicon	-
[9]	Circular Ring	0.55-0.65	1.5	-	Graphene	190
[10]	Hexagonal circular Disk	35-40	1.6	-	Graphene	-
[12]	Flower shaped	3.69-9.77	7	-	Graphene	-
[20]	Two split ring Metal resonator	3.1-5.45	1.6	-	Graphene	5000nm/RIU
[P]	**Dual Ovel-Shaped**	**1.6-2.4**	**25**	**60**	**Graphene**	**833.33-Hemoglobin/4377.77-Urine**

5. Conclusion:

Two elliptical-ovel shaped cylindrical dielectric resonator based wideband graphene inspired reconfigurable metasurface absorber results has been discussed and compare with existing literature. This proposed MS having good absorbance (>90%) and reflectivity (<10%) in the wide frequency range (1.6-2.4THz). The proposed MS shows tunable quality (multiband-wideband) by changing of graphene chemical potential and relaxation time. This MS also useful in bio-sensing applications having high quality sensitivity and figure of merit (FOM) 833.33 and 8333 with 4777.77 and 877.77 respectively. Hence, the proposed MS is good candidate for THz sensing applications.

Acknowledgments: The authors extend their appreciation to the Deputyship for Research & Innovation, Ministry of Education in Saudi Arabia for funding this research work through the project No. IFKSURG-2-1019.

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