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Research Article

Designing Graphene-Based Antenna for Terahertz Wave Ablation (TWA) System

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Abstract
Cancer is one of the most feared health problems today. Studies on cancer diagnosis and treatment are carried out intensively. Cancer diagnosis and treatment studies with the THz radiation model have also gained popularity. In this study, a graphene-based tunable antenna is proposed for cancer diagnosis and treatment in THz radiation therapy, which is a relatively new radiation technique. A graphene-based two-layer monopole antenna is designed for 1.65THz operation frequency. A graphene ring is placed on the SiO_2 substrate (2nd layer) to change the bandwidth and radiation pattern without changing the operating frequency. Antenna performance is analyzed for reflection coefficient, realized gain, E-Field. The proposed antenna is obtained approximately %4 bandwidth. A peak gain of 8.52 dB is achieved at 1.65THz within the bandwidth. Antenna design is done in Computer Simulation Technology Studio Suite. It is expected that the results of the THz antenna will make a significant contribution to healthcare applications. The cancer treatment with THz is cheap, easy, and can be used without causing discomfort in patients.

Keywords: Graphene, antenna, terahertz wave ablation, cancer diagnosis, cancer treatment.

Terahertz Dalga Ablasyon (TWA) Sistemi için Grafen Tabanlı Anten Tasarımı

Öz

Kanser, günümüzün en korkulan sağlık sorunlarından biridir. Kanser tanı ve tedavisine yönelik çalışmalar yoğun bir şekilde yürütülmektedir. THz radyasyon modeli ile kanser teşhis ve tedavi çalışmaları da popülerlik kazanmıştır. Bu çalışmada, nispeten yeni bir radyasyon tekniği olan THz radyasyon tedavisinde kullanılmak üzere kanser teşhisi ve tedavisi için grafen tabanlı ayarlanabilir bir anten önerilmiştir. Grafen tabanlı iki katmanlı monopol anten, 1.65THz çalışma frekansı için tasarlanmıştır. Çalışma frekansını değiştirmeden bant genişliğini ve radyasyon modelini değiştirmek için SiO_2 substratı (2. katman) üzerine bir grafen halkası yerleştirilir. Anten performansı yansıma katsayısı, kazanç, E-alan için analiz edilir. Önerilen anten yaklaşık olarak %4 bant genişliğine sahiptir. Bant genişliği içinde 1.65THz'de 8.52 dB'lik bir tepe kazancı elde edilir. Anten tasarımı Computer Simulation Technology Studio Suite yazılımı kullanılarak yapılır. THz anteninin sonuçlarının sağlık uygulamalarına önemli katkı sağlaması beklenmektedir. THz ablasyon ile kanser tedavisinin maliyeti uygun, kolay ve hastalarda rahatsızlık yaratmadan kullanılabilirdir.

Anahtar Kelimeler: Grafen, anten, terahertz dalga ablasyonu, kanser teşhisi, kanser tedavisi

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1. Introduction

Light, an electromagnetic wave, is divided into various categories such as visible, infrared, and ultraviolet according to frequency. The studies have shown that a frequency band (0.1-10THz) has a high potential for many applications in real life [1]. Cancer, one of the causes of early death, is one of today's most common health problems. Intensive studies are carried out on cancer diagnosis and treatment worldwide. In recent years, promising studies have been carried out to show significant success in treating THz radiation and cancer diagnosis. However, this subject is relatively new and has not yet completed its literature stage. The common features of thermal ablation techniques are the application of thermal energy to a tissue to create destruction on the tumor tissue. The method to be used is usually determined according to the requirements. The Industrial, Scientific and Medical (ISM) bands have a higher frequency source for cancer cells therapy. In this research, we proposed a graphene-based antenna to used the use the high frequency (THz) bands of the ISM bands application to soft tissues, such as liver, breast cancer therapy.

The terahertz (THz) frequency range covers an area of the electromagnetic spectrum between the infrared and microwave. A certain energy level is required to ionize or remove valance electrons from biological molecules. THz photons' energy (a few eV) is below this level. Therefore, THz rays are in the non-ionizing radiation class. While non-ionizing radiation causes local temperature increases in biological tissues, it does not generate free radicals. Almost all cancer cells are found anomalous DNA methylation, so its detection is also significant for cancer diagnosis and elimination. In cancer study, determining DNA methylation using Terahertz radiation is considered a powerful new method. DNA methylation is seen as a fingerprint for various types of cancer. And it can be directly observed at about 1.65 THz with terahertz spectroscopy. It is also believed that 1.65 THz radiation will play an essential role in the early diagnosis and treatment of cancer [2, 3]. Therefore, 1.65THz is preferred as the operating frequency in this study. Due to the THz frequency range characteristics, such as wide bandwidth and high data transfer rate, a new research focus has been placed on this topic [4]. According to literature studies, graphene material is frequently used for THz frequency in planar technology [5, 6]. Graphene’s adjustable electrical properties provide a significant advantage in developing micro and nano-sized devices [7]. In addition to adjusting the electrical length in antenna applications, the variable values of the applied electrostatic voltage help adjust the surface conductivity of graphene and, therefore, the frequency response of the devices [8]. According to literature studies, antennas made using graphene material are broadband [9], high radiation efficiency [10], broadband range [11], omnidirectional radiation model [12], as well as different characteristics. This study aims to present a Graphene-based antenna design with high-performance values operating at 1.65THz for TWA, where research has started to be investigated recently for use in cancer treatment and detection.

2. Material and Methods

2.1. Antenna Design

2.1.1. Graphene model

In recent years, electromagnetic researchers have used graphene in antennas, filters, transistors, etc., to achieve better performance with smaller element sizes. The adjustable conductivity value of graphene is significant for many applications. For example, graphene-based nano-antennas [13], THz frequency generation [14], THz filters [15] are a few examples. Using

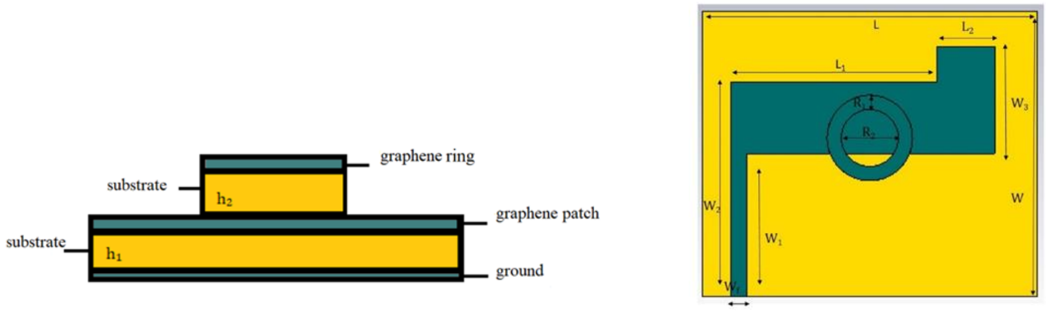
Kubo formalism, surface conductivity calculations of an infinite graphene layer are available in the literature [13]. In addition, using the Drude-like form, the frequency dependence of the surface conductivity of the graphene layer can be shown [16]:

$$\sigma(\omega) = \left(\frac{2e^2}{\pi h}\right) k_B T ln[(2\cosh\frac{\mu_c}{2k_B T})]i/(\omega + i\tau^{-1})$$

where k_B is the Boltzmann's constant, e denotes the charge of an electron, ω is the angular frequency, τ is the relaxation time, h is the reduced Planck's constant, T is the temperature in Kelvin, and μ_c ıs the chemical potential of graphene. By applying chemical doping or electrostatically biasing techniques, the chemical potential (μ_c) can be adjusted. This feature makes it easy to change the radiation properties, complex surface impedance of graphene, etc. Thus, resonance frequency, amount of absorbed power, surface conductivity, and impedance value can be changed with the help of μ_c [17]. Graphene material is available in the Computer Simulation Software (CST) Microwave Studio program library for various applications. For our antenna design, graphene plates are considered at temperature T = 300 K, a thickness of 30 nm, and have a relaxation time τ=1 ps.

2.1.2. Antenna geometry

In the study, the graphene-based monopole antenna is designed using a double layer silicon dioxide SiO_2 ($\varepsilon_r = 3.9, h_1 = h_2 = 1.2\ \mu m$) the substrate to obtain a resonance frequency at 1.65 THz. In the first layer, a folded dipole antenna is designed according to the wavelength calculated for the operating frequency. The square or rectangular patches are preferred because they can be analyzed and manufactured easily. A graphene ring is placed on the SiO_2 substrate (2nd layer) to change the bandwidth and radiation pattern without changing the operating frequency. Thus, the performance parameters required for the health application can be tuned without affecting the antenna resonance. The graphene ring put on is in an independent layer creates a non-radiating feature; by applying external DC voltage around it, it regulates the surface current density of the graphene patch. The radiation characteristics of the proposed antenna are restructured. The design views of the proposed antenna are shown in Figure 1. The antenna dimensions are given in Table 1.



a) b)

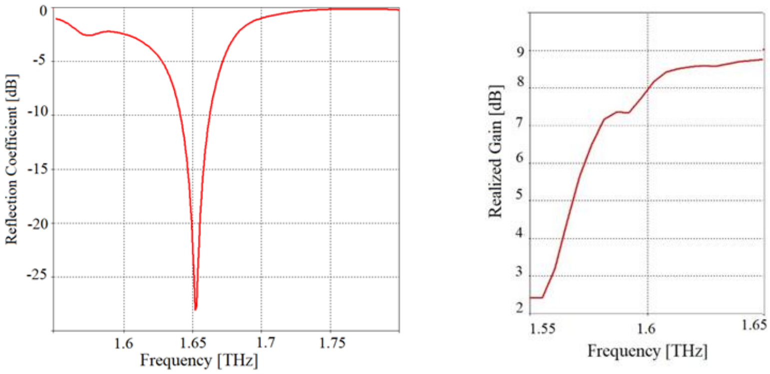
Figure 1. a) side view b) top view of the proposed graphene antenna.

Table 1. The antenna dimensions.

Parameters	L	L_1	L_2	W	W_1	W_2	W_3	W_f	R_1	R_2
Dimension (µm)	65	40	9	48	28	32	14	0.8	0.7	7

3. Results and Discussion

Using the CST simulation, an antenna with an operating frequency of 1.65 THz is designed, and its performance parameters are examined. The reflection coefficient S_{11} of the graphene-based monopole antenna is shown in Figure 2 (a). The S_{11} of the designed antenna is -28.7056 dB, as shown in Figure 2(a), which means that it can radiate effectively. A % 3.67 impedance bandwidth is obtained in the antenna operation band. It is observed from Figure 2(b), the proposed antenna has a peak gain of 8.52 dB at 1.65 THz. In Table 2, the performance parameters of the proposed antenna are compared to the graphene-based antennas summarized in the literature. The efficiency and gain values are higher than the antennas given in the literature.



a) b)

Figure 2. Graphene antenna performance parameters a) Reflection coefficient, b) Realized gain.

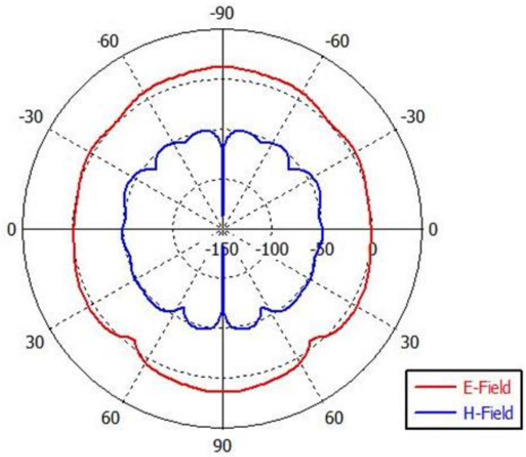


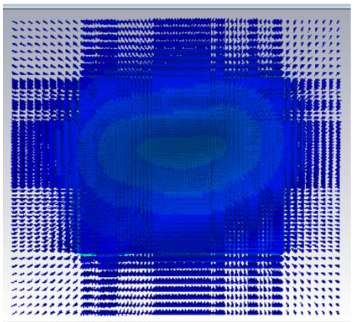
Figure 3. The radiation patterns of the antenna for 1.65 THz operating frequency.

Table 2. The literature comparison of graphene-based antennas.

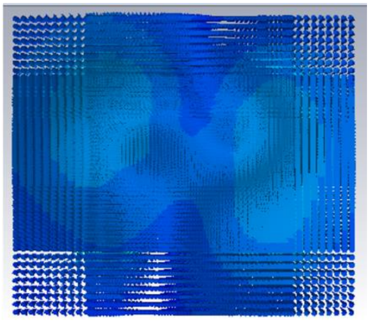
References	Resonant Frequency (THz)	Gain(dB)	Radiation Efficiency (%)	Application
[18]	7.32	7.39	84	Communication
[19]	0.46-1.6	NA	NA	Communication

[20]	257.04	3.336	NA	Cancer Detection
This work	1.65	8.52	89	Cancer Detection and Treatment

The E-field and H-field radiation pattern simulation results of the proposed graphene-based antenna are shown in Figure 3. It provides dipole-like patterns at a resonant frequency of 1.65 THz, omnidirectional in the H plane and in the E plane. The antenna resonance frequency can be adjusted in the desired range by applying the gate voltage on the graphene patch [8]. However, the basic need for health applications is to change the radiation characteristic by keeping the operating frequency constant. For this reason, the proposed antenna for healthcare applications is designed as a multilayer, and a patch with a graphene ring is placed to change the radiation characteristic without changing the antenna's operating frequency. The radiation characteristic of the antenna can be directed in the desired direction by applying a gate voltage to the graphene ring. The application of gate voltage changes the surface conductivity of graphene. Thus, changes in antenna parameters, which depend on the conductivity, can be obtained more easily. Applying a gate voltage anywhere around the graphene ring changes the direction of the radiation, changing the Fermi level of the nearby graphene patch [17]. The antenna's radiation pattern can be investigated by analyzing the near-field distribution. First, the gate potential of the graphene ring is held at 0 V. A gate voltage of 0-5V is then applied. A gate voltage of 0-5V is then used in 1-volt increments. The effect of gate voltages applied from different locations on the graphene ring on the E-field distribution is given in Figure 4 for the 1.65 THz resonant frequency. The resulting E-field distributions show that the graphene ring does not affect the near-field distribution of the antenna before the external gate voltage is applied (at 0V). According to the simulation results, it is believed that the antenna can be used in TWA applications at 1.65 THz, with its omnidirectional, high gain and efficiency values.



a)



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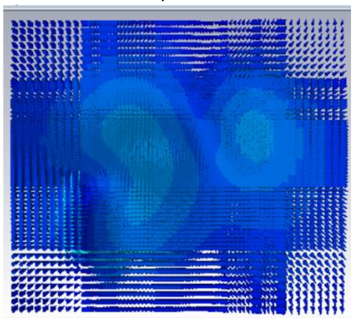
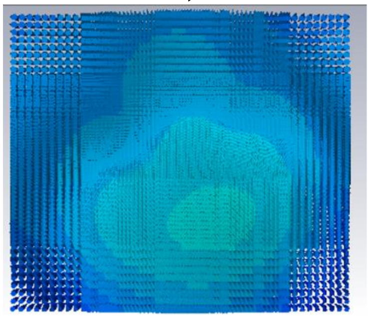
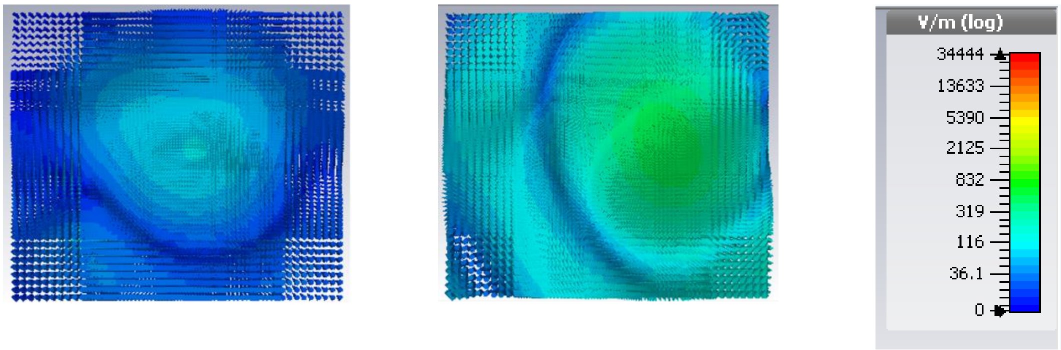


c)



d)



e) f)

Figure 4. E-field distribution on the graphene patch at 1.65 THz frequency a) without external voltage, b) 1V, c) 2V, d) 3V, e) 4V, and f) 5V.

4. Conclusion

In the study, a graphene-based tunable compact antenna is proposed for cancer diagnosis and treatment with THz radiation. A multilayer monopole antenna is designed with graphene to change the bandwidth and radiation pattern without changing the operating frequency. Antenna performance is analyzed for operating frequency 1.65 THz. The proposed antenna is obtained approximately %4 bandwidth, a peak gain of 8.52 dB is achieved at 1.65 THz within the bandwidth. This technology is not currently used in daily life, but its potential is high. Compact size and high-performance antennas have to develop for this technology to be applicable. It is expected that the results of the THz antenna will make a significant contribution to healthcare applications.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

M. Dilruba GEYIKOGLU: antenna design, simulations, article writing; Hilal KOÇ POLAT: antenna design; Bulent CAVUSOGLU: evaluation of results; Mehmet ERTUGRUL: material selection, evaluation of results ; Karim ABBASIAN: evaluation of results.

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