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Hybrid graphene–copper UWB array sensor for brain tumor detection via scattering parameters in microwave detection system

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Abstract Hybrid graphene–copper ultra-wideband array sensor applied to microwave imaging technique is successfully used in detecting and visualizing tumor inside human brain. The sensor made of graphene coated film for the patch while copper for both the transmission line and parasitic element. The hybrid sensor performance is better than fully copper sensor. Hybrid sensor recorded wider bandwidth of 2.0–10.1 GHz compared with fully copper sensor operated from 2.5 to 10.1 GHz. Higher gain of 3.8–8.5 dB is presented by hybrid sensor, while fully copper sensor stated lower gain ranging from 2.6 to 6.7 dB. Both sensors recorded excellent total efficiency averaged at 97 and 94%, respectively. The sensor used for both transmits equivalent signal and receives backscattering signal from stratified human head model in detecting tumor. Difference in the data of the scattering parameters recorded from the head model with presence and absence of tumor is used as the main data to be further processed in confocal microwave imaging algorithm in generating image.

MATLAB software is utilized to analyze S-parameter signals obtained from measurement. Tumor presence is indicated by lower S-parameter values compared to higher values recorded by tumor absence.

1 Introduction

In 2030, around 13.2 million people worldwide will suffer and die because of cancer since cancer is one of the most complex diseases in the world [1]. Early cancer detection which allows early cancer treatment could increase the cure rates as the treatment is more efficient and effective compared with treatment done at the late stage of cancer. Conventional X-ray, magnetic resonance imaging (MRI), computed tomography (CT scan) and ultrasound technique are the common imaging modalities utilized to detect cancer [2]. Microwave cancer imaging provides several substantial benefits that are not offered by other imaging techniques such as it is a fast, safe, low-cost, noninvasive technique, involves nonionizing radiation and has high accuracy in detecting tumor existence [3].

Generally, microwave imaging system used the tomography and radar-based techniques for detection purpose. Radar-based techniques are preferable since they only need to identify strong scattering point caused by inclusions with highly frequent occasion [4, 5]. This kind of technique is less complicated which involves less sophisticated algorithm of delay and sum confocal microwave imaging algorithm. This is the most common algorithm used in ultra-wideband radar-based microwave imaging technique.

Graphene functioned as the radiating material has obtained great interest among the communication device community lately. Graphene has a great potential to replace conventional patch material such as copper since detailed
analysis completed by [6] found that graphene patch antenna’s overall performance is completely better than single-wall CNT, multiwall CNT and copper patch antenna due to several advantages such as it is nanoscale sized (0.33 nm), is a great conductor ($10^8$, electron travel 1/100 speed of light), is the lightest material (0.77 mg/1 m) and is the strongest material (150,000,000 psi; 300 × stronger than steel) due to the single layer of carbon atoms packed in a two-dimensional honeycomb lattice structure. These features lead to higher gain and energy production for better penetration capability.

In this paper, graphene-based radiating material combined with conventional copper is presented as the sensor to detect human brain tumor. The graphene element is present purposely to optimize the antenna performance (higher gain) and realize ultra-wideband (wider bandwidth) in order to penetrate multistructure human head so that the signal could reach the tumor inside brain. Wide range of operated frequency is required in human microwave imaging for the signal to pass through since human structure consists of different multilayer structures with different characteristics [7]. Thus, a new hybrid graphene–copper UWB array sensor is proposed.

2 Hybrid graphene sensor design and characterization

Figure 1a shows the physical appearance of the graphene film. The film has 97% of carbon content, thickness of 25 μm and conductivity of $35 \times 10^8$ s/m [8]. The film is manually cut into desired shape and size as the patch and attached to the substrate using conductive epoxy glue as shown in Fig. 1b.

Graphene films usually have nanoscale features. In order to determine the morphology and structure of graphene, the magnifier device such as FESEM must be associated with a small beam spot size with high spatial resolution. Figure 2 shows the FESEM image of graphene film with 120,000 times of magnification. The micrometer-scale image displayed smooth, uniform and continuous layered surface, indicated good structure and indicated the graphene film as ideal for the patch for the sensor.

In graphene, the Stokes phonon energy shift caused by laser excitation creates two main peaks of G band (1580 cm$^{-1}$) and 2D band (2690 cm$^{-1}$) of a primary in-plane vibrational mode and a second-order two-phonon process, respectively, in Raman spectrum [9] as shown in Fig. 3. Since the main spectral feature of graphene is derived from in-plane motion of the carbon atoms, the peaks would appear at G band that is extremely sensitive to strain effects and is also a good indicator of the number of graphene layers. As the number of layers increases, the G band position shifts to lower frequencies [10].

Meanwhile, Fig. 4 shows the geometry of the hybrid graphene–copper UWB sensor. Figure 4a illustrates the proposed hybrid sensor before graphene sheet is applied as the patch for the sensor. Four identical circular patches of new material, graphene-coated film, copper quarter-wave transmission line and parasitic element construct the complete unique hybrid structure of the proposed sensor. Small dimensions of 90 mm × 45 mm

![Fig. 1 a Graphene-coated film, b conductive epoxy glue](image)

![Fig. 2 FESEM image of graphene sheet](image)

![Fig. 3 Raman data of graphene sheet](image)
made the UWB sensor suitable enough to be integrated as the sensor in microwave imaging system. Equal current distribution toward all four graphene patches is observed by using the quarter-wave transformer impedance matching technique. Quarter-wave transformers of 70.71 $\Omega$ are used to have ideal match between the 100 $\Omega$ lines and the 50 $\Omega$ lines [11].

The graphene patches’ diameter is 15 mm, and their parasitic element has width and length of 8 mm and 32 mm, respectively, as shown in Fig. 4b. Meanwhile, Fig. 4c indicates the partial ground plane dimension: 18 mm width and 90 mm length. On the other hand, copper reflector with 20-mm gap that functioned to reduce the side lobe and realized the directional antenna which has higher gain property [12] is shown in Fig. 4d. The size of the reflector is similar with the size of the sensor. Taconic (TLY-5) with a dielectric constant $\varepsilon_r = 2.2$, a thickness $t = 1.5748 \pm 0.02$ and tangent loss $\tan \delta = 0.0009$ is used as the substrate.

The simulated surface current indicated that the copper transmission line is electrically connected with the graphene patch since the electron is continuously moving starting from the feed port as the source and passes through the transmission line before reaching the patch and radiates outwards as the electromagnetic energy as shown in Fig. 5. The simulated surface current is obtained from the simulation process done using transient solver of CST Design Studio software. Figure 5 shows that the solver is capable of providing real time domain simulation that is useful for studying the electrical field propagating within the sensor between two different materials of copper and graphene. There is less or very minimum declination of current flow between two different mediums of copper and graphene.

The hybrid sensor performance is better than fully copper sensor performance. The sensor recorded ultra-wideband microwave radiation to be less than $-10$ dB starting from 2.0 to 10.1 GHz and 2.5 to 10.1 GHz for hybrid and fully copper sensors, respectively, with higher energy transmitted by hybrid sensor ranging from 3.8 to 8.5 dB compared with fully copper sensor which recorded gain of 2.6–6.7 dB as shown in Fig. 6.

Figure 7 shows the polar radiation pattern in azimuth plane for the proposed sensor at the frequency of 3, 4, 5 and 6 GHz. These four particular frequencies are recorded among the highest gain of the antenna. The radiation pattern indicates both hybrid and fully copper sensors do radiate over a wide frequency band [13] where hybrid sensor recorded better radiation pattern indicated by wider area covered especially the main lobe. The sensor exhibits the averaged total radiation efficiency of 94 and 97% for fully copper and hybrid sensors, respectively. The high
the production of high-energy radiation [14] to be illuminated toward the tumor in order to produce scattering signal. Taconic substrate is an electrical medium which generates the electric flux inside the substrate [15], providing the optimum results of radiation characteristic, bandwidth and size. The low value of permittivity leads to wider bandwidth and high radiation efficiency. Figure 8 illustrates the measurement setup for brain tumor detection using microwave radar imaging technique.

The hybrid graphene–copper sensor is perfectly placed 10 mm away from the multilayer human head phantom to have maximum signal penetration. The sensor radiated the signal toward two different types of human head phantoms one with tumor meanwhile the other without the tumor to obtain the difference in scattering parameter values. Tumor represented by the mixed liquid as shown in Table 1 has similar dielectric permittivity as the real brain tumor ($\varepsilon_r = 63$) located inside the human head phantom as shown in Fig. 10. The sensor radiated the signal toward nine different areas to cover the whole one-sided area of those two phantoms as shown in Fig. 9. Data of both with and without tumors are subtracted from each other, and the difference obtained is then processed in order to produce the desired image.

Human head phantom is developed using four-layer rectangular box container made of Plexiglas ($\varepsilon_r = 2.3$) filled by tissue simulating materials as shown in Fig. 10. This container is partitioned into dimensions of the head tissues structure with the brain region as the center, the first surrounded by the skull layer followed by fat layer and skin layer as the outer most layers. The brain region has the dimension of 170 mm $\times$ 140 mm, skull thickness layer of 10 mm and skin and fat layer thickness of 5 mm each. Each tissue is separated by 1 mm thickness.

Broadband simulating liquids which have same dielectric properties of permittivity of the human head tissues including the tumor are prepared. The major constituents of

3 Results and discussion

3.1 Methodology and discussion

High electrical conductivity of graphene (108 s/m) [6] and low electrical permittivity of Taconic substrate (2.2) enable

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**Fig. 6** Measured reflection coefficient and gain comparison between fully copper and hybrid UWB sensors

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**Fig. 7** Measured polar radiation pattern in azimuth plane; red (hybrid) and blue (fully copper), a 3 GHz, b 4 GHz, c 5 GHz and d 6 GHz

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amount of total radiation efficiency of the sensor indicates the effectiveness of the sensor to be applied for human brain microwave imaging.
the liquids are water and Tween 20 which are mixed in different ratios to achieve the dielectric properties of the head tissues in the frequency range of 1–5 GHz. The liquids are nonreactive, harmless and safe for handling. The compositions of the mixtures are given in Table 1.

Meanwhile, Table 2 gives the comparison values of the measured permittivity and the target permittivity of tissue simulating materials. The measured error values are minimal and within acceptable range. The permittivity targeted value for those structures is obtained from Italian National Research Center database [16].

The Agilent 85070E liquid dielectric probe kit and Agilent Portable VNA E5071C are used to measure the related dielectric properties as shown in Fig. 11.

Figure 12 illustrates the measurement setup for the brain tumor detection using microwave radar imaging technique.

It consists of the VNA, RGO antenna and human head phantom. Measurements are performed in anechoic chamber to minimize interference.

In order to have clearer overview and easier in analyzing results, data in frequency domain are necessary to be converted into correspond time domain in providing real-
time values against reflection coefficient values. These real-time values are then utilized in determining the distance between the antenna outside the head model and the respective tumor located inside the head model. These distances values can be used in predicting the existence of tumor by calculating intensity values to produce intensity images by mapping the points of the strong scattering signal.

Figure 13 shows the flowchart of the confocal microwave imaging algorithm for data generation and image construction. MATLAB software is used to process the data obtained using confocal imaging algorithm.

3.2 Measurement results and discussion

In this paper, the presence of tumor is detected based on the reflection coefficient graph. It is expected that higher reflection coefficient values will be shown as indicator for a presented tumor. The microwave signals are transmitted from the hybrid graphene–copper sensor into two different situations of human head phantom. First, the transmitted signals flow into head human phantom without any obstacles (without tumor) and then followed by filling-up the obstacle (with tumor) within the head phantom. As previously mentioned, the presence of tumor could be detected by observing the change in magnitude of the reflection coefficient graph as can be seen in Fig. 14a, b.
There are obvious differences in reflection coefficient values when tumor has been inserted only at position 2. Higher reflection coefficient values are demonstrated at position 2 compared with the two other positions 1 and 3. Such results prove that the presence of tumor generates higher magnitude of reflection coefficient due to the blockage toward the transmitted signals made by the tumor itself. This can be further verified by locating the hybrid graphene–copper sensor at position of 4, 5, 6, 7, 8 and 9 while maintaining the tumor at position 2 (see Fig. 9). According to the graph, it illustrates clearly that there are no differences between with and without tumor conditions for each particular position.

4 Conclusions

Brain tumor detection through microwave imaging system is successfully done. High performance of hybrid sensor as the signal transmitter and receiver or as the scanning probe assists in realizing it. The presence of tumor resulted in lower reflection coefficient values compared with without the presence of tumor in human head model. The final results clearly show the differences between healthy brain and brain with tumor.

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