A DESIGN OF PATCH ANTENNA OPERATED IN ULTRA HIGH FREQUENCY WITH GRAPHENE AND TITANIUM DIOXIDE

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ABSTRACT

In this paper, a new design of graphene, titanium dioxide (TiO_2) based-rectangular patch antenna is simulated and tested in free space environment. The advantages of graphene and TiO_2 include a biocompatibility of these materials, which is useful in medical applications. The results of simulation reported the return loss (S_{11}) of rectangular patch antenna comparing among various crystallographic polymorph phases of TiO_2 and various types of graphene. The results suggested that the best combination of graphene-TiO_2 rectangular patch antenna was made of TiO_2 in rutile phase that annealing at 850°C as dielectric substrate, graphene-based conductor sheet as patch, and graphene paper as ground.

1. INTRODUCTION

Nowadays implantable telemetry devices have an important role in wireless communication between the implantable devices and doctor/medical reader instruments. An orthopedic implant is a medical device that used to fix or replace a damaged bone with the artificial bone, joint, or plates for example, Baksi's prosthesis for elbow replacement, Baksi, D. P., et al. (2009). In the previous study, the orthopedic implant was embedded with a sensor to measure a physiological activity inside the body, Stover, H. H. (2004). The implantable device is usually made from biocompatible materials which are materials that does not harmful with the living cells. Such materials can be a natural synthetic or composite materials that when being in contact with living cells or tissues does not cause an adverse effect. An antenna was used for wireless communication in the sensor-monitoring device, embedded to the orthopedic implant, e.g. an implantable 9-channel telemetry system for in vivo monitoring system, Graichen, et al. (2007). In that study, the loop antenna which is made from niobium wire was covered with polyether ether ketone cap at the stem tip of hip implants. This hip implant is designed for detecting the pressure signals via external monitoring system while patients walked at a high sampling rate, which could be used in long term-measurement without any post operation. However, this investigations can recruit a few of patients due to the application has some restricted in stationary transmission in experiments. Although the antenna usually made from metallic materials gave a desirable efficiency, it was not suitable to use with living cells because of toxicity from metal corrosion. In this work, we use biocompatible materials, specifically graphene and TiO_2, as based-materials in the design of patch antenna. The antenna was stimulated in a frequency range of 1-12 GHz for a possible use in biomedical devices at the industrial, scientific and medical radio bands.

2. MATHEMATICS & SIMULATION

2.1 Theory & mathematical models

A patch antenna has three compartments, including patch, dielectric substrate, and ground plane. The shape that used in this work is rectangular because of an ease of fabrication and analysis. Since the heights of patch and ground are usually very thin, therefore, its dimension is evaluated only width and length. The dielectric substrate and ground plane have the same width and length. However, the height of the dielectric substrate is considered in this work, because it is the main thickness of the patch antenna. The material of the patch and ground are graphene and dielectric substrate is TiO_2. Graphene has a good electrical conductivity and mechanical property. It has a unique behavior in electrical properties because of its electronic structure that being gapless, Fatikow, S., et al., (2012). It is also a biocompatible material that can support cell attachment, growth and proliferation, Bressan, E., et al., (2014). TiO_2 is an oxide of titanium when being in contact with water and air. Titanium and its alloys are biocompatible materials, widely used in orthopedic applications. An antenna with thick substrate that has low dielectric constant provides highest efficiency in theory, Balanis, C. A. (2005). TiO_2 has broad range of dielectric constant, from 17 to more than 100 depending on crystallographic polymorph phases of itself, Wypych, et al. (2014). In some phase, TiO_2 is suitable to use as dielectric substrate of the patch antenna, Santos, E. J. G., et al., (2013). The patch antenna has a phenomenon, called a fringing effect, which is a function between width of patch and height of dielectric substrate that affects to a resonant frequency. The height (h) of antenna or dielectric substrate was determined by free-space wavelength (λ_0). The width size of patch (W) is relative with the dielectric constant (ϵ_r) of dielectric substrate since the electric field line is in z-y plane.

$$W = \frac{\nu_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

Where ν_0 is a velocity of light in free space, and f_r is a frequency range used in this work. The width of patch from equation (1) is used to calculate an effective dielectric constant (ϵ_{reff}), which is a dielectric constant of air and substrate that the electric field line propagates in z-y plane. The equation is shown in equation (2).

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (2)$$

The effective dielectric constant (ϵ_{reff}) is used to determine the effective length that caused from fringing effect. The electrical length of patch is greater than the physical dimension. The extended length (ΔL) can be determined by equation (3) and is used to calculate an effective length (L_{eff}) of patch later with equation (5).

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad (3)$$

The other variable used to determine the effective length (L_{eff}) is an actual length of patch (L), which is relative with the free space wavelength (λ_0), as determined by equation (5).

$$L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L \quad (4)$$

From equations (3) and (4), the effective length (L_{eff}) of patch effected by fringing effect can be determined by equation (5).

$$L_{eff} = L + 2\Delta L \quad (5)$$

The ground dimension is usually larger than the patch dimension about six times of thickness of dielectric substrate, as shown in equation (6) for width of ground and in equation (7) for length of ground. A model of rectangular patch antenna is shown in Fig. 1.

$$W_g = 6h + W \quad (6)$$

$$L_g = 6h + L \quad (7)$$

Then, the obtained values of W, L, h, W_g, and L_g are used in computer simulation. The results were reported as return loss (S_{11}) of the graphene-TiO_2 based patch antenna.

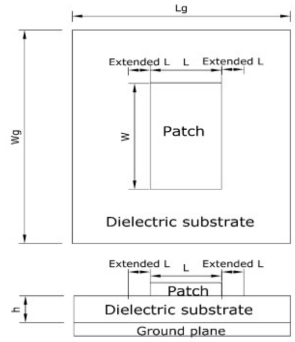

Fig. 1 The layouts of patch antenna with a rectangular shape: (A) a top view shows the areas of patch, L, W and extended L (ΔL) and dielectric substrate, W_g and L_g; and (B) a side view shows the layers of patch, thickness of dielectric substrate (h) and ground plane.

2.2 Simulation method

Simulation software was an EMCoS Antenna V Lab SV v1.0.1. The antenna model was simulated in free-space environment in a frequency range of 1-12 GHz, and also observed at a working frequency of 2.5 GHz. The constant parameters were velocity of light (ν_0), 3.0×10^8 (m/s), free-space wavelength (λ_0), 120 mm, and the thickness of substrate obtained from equation (1), 6 mm. The position of feed point in the patch antenna was at the center, as reported in the previous work, Fugto, N. et al. (in press). The other variables included dielectric constant of TiO_2 (ϵ_r), thickness and electrical conductivity of graphene. The return loss (S_{11}) from simulation suggests the efficiency of patch antennas. Since phases of TiO_2 (dielectric substrate) could affect to the overall dimension of antennas, as shown in equations (1)–(7), only the one with the best return loss (the least value) was chosen in further simulation. Such dielectric substrate was later fixed as dielectric substrate. The effect of various thicknesses and electrical conductivities of graphene patches toward return loss of antennas was also studied.

2.2.1 Various crystallographic polymorph phases of TiO_2 as dielectric substrates

The dielectric constants of various crystallographic polymorph phases of TiO_2 were reported by Wypych, et al. (2014). TiO_2 materials obtained from different preparation methods had different characteristics and properties, such as relative density and dielectric constant. Various TiO_2 substrates with their dielectric constants used in this work are in table 1. In simulation, the patch was as commercial graphene-based conductor sheet, Graphene-supermarket.com (2015). While the ground was graphene paper; the dielectric constant and conductivity of these two graphene materials can be found in table 3. The dimensions of patch antennas, obtained from the mathematical model when used five dielectric substrates (table 1), were reported in table 2.

Table 1 Crystallographic polymorph phases and dielectric constants of TiO_2 prepared from different methods

Titanium dioxide (Annealing temperature)	Dielectric constant (ϵ_r)
Anatase (600°C)	18.9
Anatase-Rutile (900°C)	17.0
Rutile (850°C)	23.0
Rutile (900°C)	43.2
Rutile (850°C)	63.7

Table 2 Dimensions of patch antennas calculated from five dielectric constants of TiO_2.substrates

Dielectric constant (ϵ_r)	W(mm)	L(mm)	W_g(mm)	L_g(mm)
17.0	20.0	12.3	56	48.3
18.9	19.0	11.6	55	47.6
23.0	17.3	10.3	53.3	46.3
43.2	12.8	6.8	49	42.8
63.0	10.5	5.1	46.5	41.1

2.2.2 Various graphene nanomaterials as patches

Graphene has an excellent electrical conductivity in a single layer, but a stack of graphene layers, like graphite, has a low conductivity. The relationship of graphene thickness and its electrical conductivity was reported earlier by Marinho, et al (2012), Al-Hartomy, O. A., (2012) and Sajal, S. Z. (2015). The increase of layer number relates to the decrease of electrical conductivity of graphene, as shown in table 3, graphene single layer (GSL), graphene nanosheets (GNs) and graphene paper (GP). However, there are commercial product that can manipulate the graphene sheet with higher conductivity than usual, called graphene-based conductor sheet (GC), Graphene-supermarket.com (2015). These various type of graphene products all were simulated as patch, while graphene paper was set as ground. It is because of the ground should have enough thickness to reflect the receive signal and cause the radiation field.

Table 3 Various graphene nanomaterials with thicknesses and electrical conductivities.

Graphene	Thickness (nm)	Conductivity (S/m)
GSL	0.335	1×10^8
GNs	3.4, 100	1.098×10^7, 6.8×10^5
GC	2.5×10^4	1.94×10^5
GP	3×10^4	1.4×10^3

3. RESULT

3.1 Effect of crystallographic polymorph phases of TiO_2 substrates

The result suggested that antenna performance was depended on dielectric constant of TiO_2, as shown in Fig 2. The return loss of TiO_2 in rutile phase (850°C) with dielectric constant of 63.7 was -35.67 dB, which is the best among all settings in this experiment. However, the working frequency was shifted from 2.5 GHz to 5 GHz. Therefore, rutile phase of TiO_2 was used as dielectric substrate in further simulation.

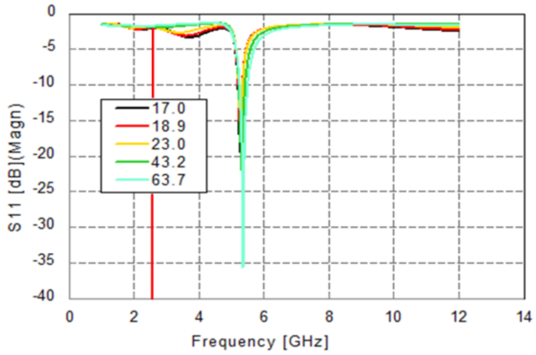

Fig. 2 Return loss of antennas simulated with various phases of TiO_2 dielectric substrate. It was shown that the blue line as rutile phase (850°C) with dielectric constant 63.7, gave a desirable return loss at -35.67 dB when compared with all other phases of TiO_2. The other TiO_2 in anatase-rutile (900°C) as black line, anatase (600°C) as red line, rutile (850°C) with dielectric constant 23.0 as yellow line, and rutile (900°C) as green line gave the return loss -19.40 dB, -16.92 dB, -15.14 and -21.98 respectively. The red vertical line is set at the frequency of 2.5 GHz.

3.2 Effect of various graphene patches

The TiO_2 rutile phase (850°C) with dielectric constant of 63.7 was used as dielectric substrate of patch antenna, while graphene paper (GP) was used as ground. The effect of thickness and type of graphene to its electrical conductivity was observed with the return loss of patch antennas, as shown in Fig 3. The patch, made by GC, overwhelm other graphene-based patch in this experiment considering the return loss of it. The results are shown that the working frequency of current design is also shifted from 2.5 GHz to approximately 5 GHz rather than similar to result in section 3.1.

CONCLUSION

The patch antenna with graphene and TiO_2 as based-materials in a rectangular shape was reported in this paper. The design was simulated with an EMCoS antenna V Lab software in free-space environment. In this study, the patch antenna can produce return loss value at -35.67 dB, when TiO_2 in rutile phase with dielectric constant of 63.7 and graphene-based conductor sheet were used as dielectric substrate and patch, respectively, while graphene paper was set as ground. The frequency shift to 5 GHz is observed in whole cases of this study. This frequency shift effect causes by the position of feed line that reduce the operating length of patch by half. As operating frequency is function of patch length (4) so the operating frequency should be doubled up. Then, the solution is extending the operating length of patch to shift operating frequency to the proper range. The further studies, focused on frequency shifting and human-body environment, are in progress.

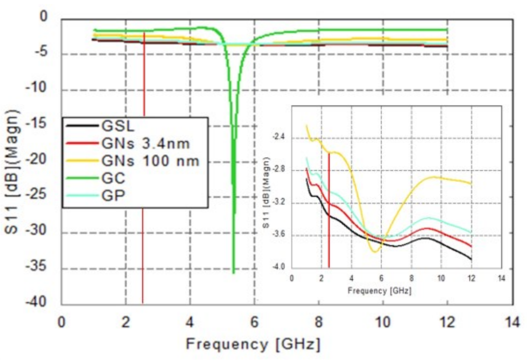

Fig. 3 Return loss of antenna simulated with various thicknesses and types of patch graphene. It was shown the green line that when patch was GC and ground was GP, the best return loss was at -35.67 dB. The inset shows return loss of GSL as black line, GNs at 3.4 nm as red line, GNs at 100 nm as yellow line, and GP as blue line, as patch that have return loss -3.67 dB, -3.62 dB, -3.80 and -3.60 respectively. The red vertical line is set at the frequency of 2.5 GHz.

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