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Transparent Patch Antenna Fabricated with Poly(3,4-ethylene dioxythiophene) Polystyrene Sulfonate (PEDOT:PSS) in 2.45 GHz

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In this research, we present an optical transparent patch antenna fabricated with poly(3,4-ethylene dioxythiophene) polystyrene sulfonate (PEDOT:PSS; PP). This patch antenna provides a peak gain at 2.45 GHz. The parameters of the patch antenna are designed on the basis of the transmission line theory. Vector network analyzers can be used to obtain a wide gap of the patch antenna, i.e., a low resonance frequency. In this study, the average transmittance of the patch antenna is higher than 88%, which is measured by ultraviolet–visible (UV/Vis) absorption spectroscopy. To increase the conversion efficiency of the patch antenna, a PP film is annealed at 220 °C to improve the conductivity. The higher the conductivity of the film, the higher the conversion efficiency of the patch antenna. The sheet resistance is increased from 216 to 80 Ω/sq. The results of S_{11}= −16 dB, gain = −8.6 dB, and efficiency = 7% are obtained using vector network analyzers and by antenna radiation pattern measurement. The result indicating that annealing improves the efficiency of the transparent patch antenna is feasible.

1. Introduction

Currently, solving the problem of energy shortage is important. Electromagnetic waves are present in the environment, and an antenna can transform electromagnetic waves into energy. The Institute of Electrical and Electronic Engineers (IEEE) 802 LAN/MAN Standards Committee formulated Wi-Fi 6 (IEEE 802.11ax), and the operation frequency included 2.45

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GHz; thus, an antenna with a resonance frequency of 2.45 GHz was fabricated.(1) In this study, a transparent patch antenna is fabricated using poly(3,4-ethylene dioxythiophene) polystyrene sulfonate (PEDOT:PSS; PP), which is an organic high-molecular-weight polymer material, and is mounted on a glass substrate. PP is composed of two components. One of the components is sodium polystyrene sulfonate, which is a sulfonated polystyrene and carries negative charges. The other component is poly(3,4-ethylenedioxythiophene), which is a conjugated polymer and carries positive charges. The advantages of PP are high conductivity, high ductility, flexibility, cheap and simple fabrication, and machinability. The patch antenna is small. It is important that the film of the patch antenna can be fabricated on any substrate. Therefore, the transparent patch antenna can be mounted on other substrates such as windshields and plastics, and does not affect visibility.

A study showed that the antenna efficiency is high but the antenna is not transparent.(2) Indium-tin oxide (ITO) is generally used as a transparent conductive film, but there are some disadvantages such as high price, brittleness, and high-temperature and high-vacuum fabrication.(3) From the above statements, PP is a good material used to replace ITO. Thus far, the energy transformation of a transparent patch antenna is small. The conversion energy of the transparent patch antenna can be accumulated by connecting the patch antenna in series or its conductivity can be improved to increase its efficiency. In this article, a detailed investigation on increasing the efficiency of the patch antenna mechanism by heat treatment is presented.

2. Materials and Methods

2.1 Antenna design

The parameters of the patch antenna are designed on the basis of the transmission line theory.(4) This design based on the transmission line theory is easy to perform. The size and feed position are chosen on the basis of this theory, and the resistance of the patch antenna is calculated with equivalent impedance. The result of the transmission line theory is an approximation. The designed antenna is a rectangular patch that resonates at 2.45 GHz.

Figure 1 shows the configuration of the patch antenna. The patch antenna with a ground length (L_g) of 60 mm and a ground width (W_g) of 60 mm is a fully PP grounded microstrip built on a transparent substrate with a dielectric constant of 2.2, and the thickness of the glass is 0.72 mm. The patch antenna has a length (L) of 40 mm, a width (W) of 47 mm, a feed width (W_f) of 2.3 mm, and a feed inset (y_0) of 9.4 mm.

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Here,

c = free space velocity of light,
ε_r = dielectric constant of the substrate.

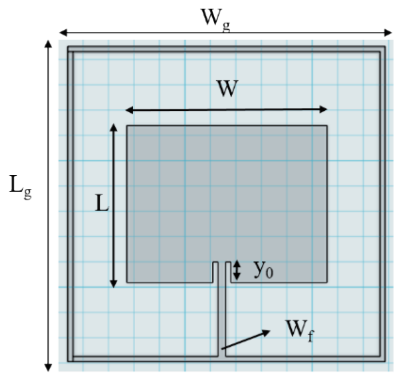

Fig. 1. (Color online) Antenna configuration.

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}} \sqrt{\mu_0 \varepsilon_0}} - 2\Delta L \tag{2}$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left[\frac{W}{h} + 0.264\right]}{\left(\varepsilon_{reff} - 0.258\right)\left[\frac{W}{h} + 0.8\right]} \tag{3}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} \tag{4}$$

Here,
ε_{reff} = effective dielectric constant of the rectangular microstrip patch antenna,
W = width of the substrate,
h = thickness of the substrate.

2.2 Process

As shown in Fig. 2, the experimental steps are as follows.

a. Solution processing: Sorbitol (0.369 g) was added to PP (PH1000) of 10 ml volume.[5]
b. Film fabrication and treatment: The glasses were cleaned with acetone, methanol, and DI water, and oxygen plasma was used to enhance its surface adhesion. Next, PP was coated on the glasses (first step: 1000 rpm for 10 s; second step: 2000 rpm for 20 s) and baked at 100 ℃ for 20 min.
c. Annealing: The film was annealed at 220 ℃ for 30 min.
d. Etching: Oxygen plasma (60 W/120 s) was used to etch the redundant PP and form the pattern of the patch antenna.

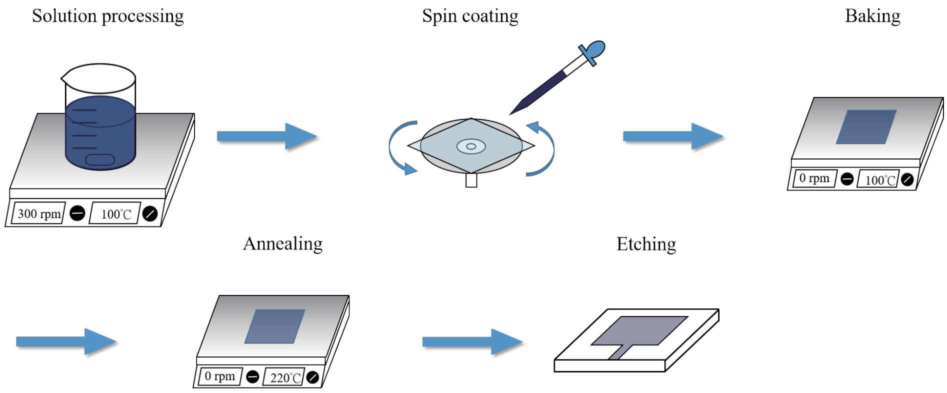

Fig. 2. (Color online) Experimental steps.

3. Results and Discussion

From the design, the patch antenna has a resonance frequency of 2.45 GHz with a −10 dB bandwidth of 375 MHz or 15.3%. Figure 3 shows the return loss S_{11} of the patch antenna plotted vs frequency. A reflection coefficient magnitude of −11.7 dB is obtained at the frequency of 2.45 GHz. Figure 4 shows the radiation patterns in the *XZ*- and *YZ*-planes of the proposed patch antenna. The main lobe is −21 dB and the efficiency of the patch antenna is 2%. The typical microstrip patch antenna has the maximum gain at the main lobe (near 0 degrees). The phenomenon is not revealed in this study because the efficiency of the patch antenna is low, resulting in the gain of the main lobe being lower than that of the side lobe. It is well known that the efficiency of the patch antenna depends on the conductivity of the PP film.

To increase the efficiency of the patch antenna, the sheet resistance of PP-sorbitol for sulphuric acid treatment should be 220 Ω/sq(6) and that of PP-sorbitol annealed at 220 °C should be 80 Ω/sq. The insulating PSS was reduced in the film skin layer after two treatments. Both PSS and PEDOT were removed after the film was treated with acid. Moreover, the sorbitol acted as a plasticizer. The level of interaction in the interchain of the PP film was decreased, and polymer chains were rearranged, resulting in the PSS being easily reduced after annealing.(7) The ratio of PEDOT to PSS increased, causing the number of connected filaments to increase sharply and the carrier transportation route to vary from three dimensions to one dimension.(8) When the annealing temperature was up to 240 °C, the sheet resistance of the film increased because PP was destroyed at high temperatures (Table 1). Figure 5 shows the radiation pattern of the annealed patch antenna. In Fig. 5(b), the gain of the main lobe is −8.6 dB and the efficiency is improved from 2 to 7%. Moreover, the conductivity is increased, leading to the increase in the gain of the main lobe.

The maximum gain of the patch antenna with a complex design is −8.6 dB.(9) We found that the maximum gain of the rectangular patch antenna is lower than that shown in Ref. 9, but after the patch antenna with the PP film is annealed at 220 °C, the maximum gain is comparable to that shown in Ref. 9. In other words, although the microstrip antenna has a low efficiency, the annealing can improve the conductivity and increase the maximum gain of the radiation pattern to as high as those in other designs.

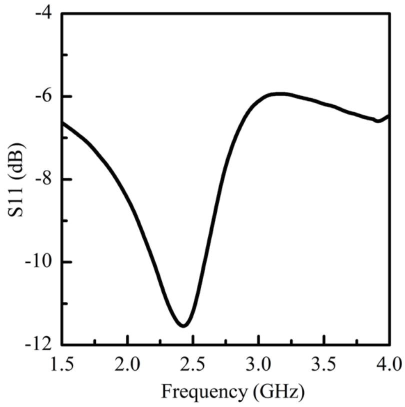

Fig. 3. Return loss S_{11} of proposed antenna.

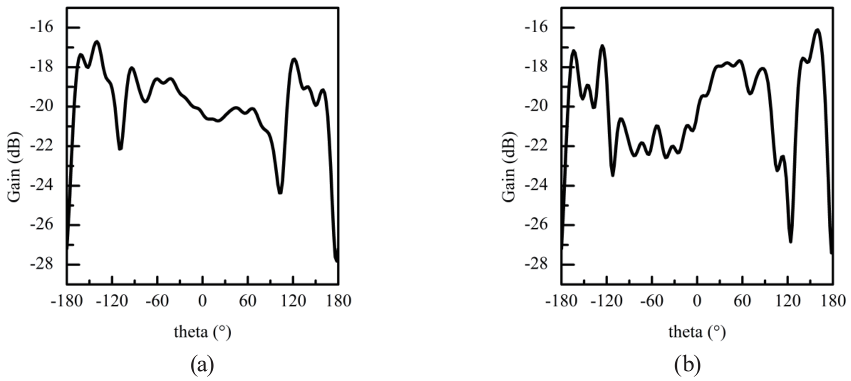

Fig. 4. Radiation patterns obtained at 2.45 GHz: (a) *XZ*-plane and (b) *YZ*-plane.

Table 1
Sheet resistances obtained after annealing at different temperatures.

Temperature (℃)	Sheet resistance (Ω/sq)
0	40000
180	176
200	143
220	80
240	185

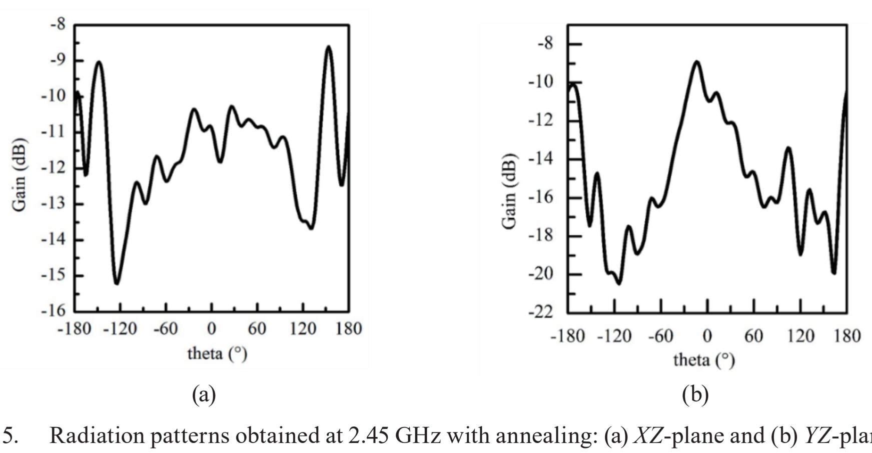

Fig. 5. Radiation patterns obtained at 2.45 GHz with annealing: (a) *XZ*-plane and (b) *YZ*-plane.

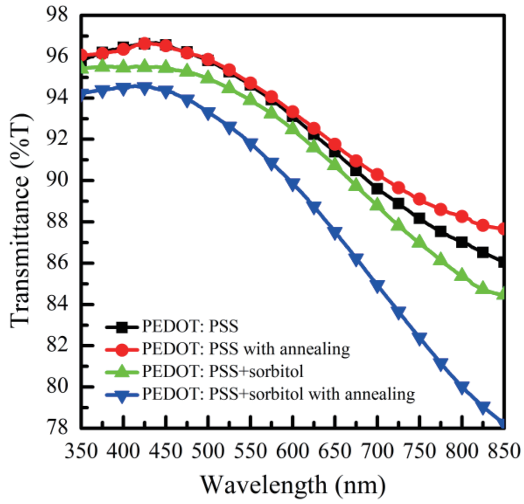

Fig. 6. (Color online) Transmittance spectra of PEDOT:PSS films with different treatments.

Figure 6 shows the transmittance spectra of PEDOT:PSS films with different treatments. It can be observed that the transmittance of the PP film slightly increases when PP is annealed because PSS is removed. The transmittance of PP-sorbitol slightly decreases because sorbitol addition can cause the chain to reorient. The transmittance of the PP film clearly decreases after annealing and sorbitol doping because sorbitol evaporates after annealing and PEDOT has a dense packing.(10) Although the transmittance of the PP film decreases in visible light, the average transmittance of the PP film is higher than 88%. In addition, PEDOT:PSS with a dense packing can also explain why the conductivity of PP increases.

This research showed that the annealed PP has potential for use in the patch antenna. Although the opaque antenna has a high efficiency, the annealed PP has a high potential to obtain a high-efficiency antenna with another configuration. Moreover, the transparent patch antenna can be used anywhere.

4. Conclusions

The design of a microstrip patch antenna is simple, and because of its light weight and easy fabrication, its potential is unlimited. In this study, the efficiency of a patch antenna is low, but the PP film has considerable plasticity. The conductivity of this material was increased by heat treatment and adding additives to improve the efficiency of the patch antenna from 2 to 7%. After annealing, the transmittance of the PP film became higher than 88%. The result showed that the PP film has the potential to obtain a high-efficiency patch antenna. Moreover, it is a promising conductor material that can transform electromagnetic waves into energy through a rectifier.

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References

1 D. López-Pérez, A. Garcia-Rodriguez, L. Galati-Giordano, M. Kasslin, and K. Doppler: IEEE Commun. Mag. **57** (2019) 113. http://doi.org/10.1109/MCOM.001.1900338
2 S. J. Chen, C. Fumeaux, P. Talemi, B. Chivers, and R. Shepherd: Proc. 2016 17th Int. Symp. Antenna Technology and Applied Electromagnetics (IEEE, 2016) 1–4.
3 C. G. Granqvist and A. Hultåker: Thin Solid Films **411** (2002) 1. https://doi.org/10.1016/S0040-6090(02)00163-3
4 B. Garg, R. D. Verma, and A. Samadhiya: IJET **1** (2012) 205. https://doi.org/10.14419/ijet.v1i3.124
5 C. J. Huang, K. L. Chen, Y. J. Tsao, D. W. Chou, W. R. Chen, and T. H. Meen: Synth. Metals **164** (2013) 38. https://doi.org/10.1016/j.synthmet.2012.12.008
6 T. H. Meen, K. L. Chen, Y. H. Chen W. R. Chen, D. W. Chou, W. H. Lan, and C. J. Huang: Int. J. Photoenergy **2013** (2013). https://doi.org/10.1155/2013/843410
7 A. K. Havare, M. Can, S. Demic, M. Kus, and S. Icli: Synth. Metals **161** (2012) 2734. https://doi.org/10.1016/j.synthmet.2011.10.011
8 X. Huang, L. Deng, F. Liu, Q. Zhang, and G. Chen: Energy Mater. Adv. **2021** (2021). https://doi.org/10.34133/2021/1572537
9 K. Guerchouche, E. Herth, L. E. Calvet, N. Roland, and C. Loyez: Microelectron. Eng. **182** (2017) 46. https://doi.org/10.1016/j.mee.2017.08.007
10 A. M. Nardes, M. Kemerink, M. M. De Kok, E. Vinken, K. Maturova, and R. A. J. Janssen: Org. Electron. **9** (2008) 727. https://doi.org/10.1016/j.orgel.2008.05.006

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