Permeability and Permittivity Measurements of Teflon in Millimeter Wave

E Handoko1*, M A Marpaung1, R Fahdiran1, Z Jalil2, and M Alaydrus1
1Dept. of Physics, Universitas Negeri Jakarta
Jalan Rawanangun Muka 13220, Jakarta, Indonesia
2Dept. of Physics, Syiah Kuala University
Banda Aceh 23111, Indonesia
3Dept. of Electrical Engineering, Universitas Mercu Buana
Jalan Moruya Selatan No.1, Jakarta, Indonesia
Email: erfan@unj.ac.id

Abstract. In order to expand a new millimeter wave absorbing material over the V-band frequency range, teflon were prepared with thickness of 1.4 mm, 1.5 mm, and 1.6 mm. The variation of electromagnetic variables (complex permeability $\mu = \mu' - j\mu''$ and complex permittivity $\varepsilon = \varepsilon' - j\varepsilon''$) properties were studied over the V-band frequency range with varying sample thickness. Both dielectric loss ($\varepsilon''$) and magnetic loss ($\mu''$) were leading to strong fluctuations, whereas the dielectric constant ($\varepsilon'$) was found to decrease and magnetic permeability ($\mu'$) increased in the frequency range of 50–67 GHz.

1. Introduction

Recently, millimeter wave (mmWave) frequencies are being used for many applications in the modern world, including telecommunications, remote sensing, defense and military applications [1–5]. The mmWaves are electromagnetic (EM) waves defined within the frequency range of 30–300 GHz. According to the formula which is given by the wavelength $\lambda = \frac{c}{f}$, where $f$ is the frequency (in hertz) and $c = 3 \times 10^8$ m/s is the speed of light, the mmWave band corresponds to a wavelength range of 1 mm at 300 GHz increasing to 10 mm at 30 GHz [1,3,5]. Thus, effective mmWave absorbers are a serious matter in the world for many applications in the gigahertz frequency. It is well-known that the EM wave absorption abilities of absorbers are crucially determined by the complex permeability and permittivity [6,7]. There are numerous research results about mmWave absorbers with its application. For example, barium hexaferrite BaFe$_{12-x}$Al$_x$O$_{19}$ ceramics [8], polymers [9], BaTiO$_3$/Co$_3$O$_4$ composite powders [1], have been successfully exhibited mmWave absorption properties. This work is to investigate the permeability and permittivity of teflon in the mmWave band 50–67 GHz. We evaluated the reflection $S_{11}$ and transmission $S_{21}$ values with a thickness $d$.

2. Experimental Method

Teflon was obtained from the Indonesia materials market and cutted with dimensions 3.76 mm×1.88 mm×1.6 mm ($\pm 0.05$) for the mmWave measurements. Teflon was measured with a Rohde Schwarz ZVA 67 vector network analyzer (VNA), which was used to find the scattering parameters ($S_{11}$ and $S_{21}$) with the WR15 sample holder in the frequency of 50–67 GHz. Base on Nicolson-Ross-Weir (NRW) method, the complex permeability ($\mu$) and permittivity ($\varepsilon$) of teflon were calculated by using S-parameters ($S_{11}$ and $S_{21}$ values) [10–12]. The VNA measurement mechanisms of teflon is illustrated in Fig. 1.
3. Results and discussion
The complex reflection ($S_{11}$) and transmission ($S_{21}$) results were measured with VNA in the frequency range of 50–67 GHz as shown in Fig. 2. The $S_{11}$ and $S_{21}$ data were used to find the complex permeability and the permittivity of teflon with thickness of 1.4 mm, 1.5 mm, and 1.6 mm through the NRW method, which is then formulated using the following steps.

$$K = \frac{(S_{11})^2 - (S_{21})^2 + 1}{2(S_{11})}$$

$$\Gamma = K \pm \sqrt{K^2 - 1}, \quad |\Gamma| \leq 1$$

$$T = \frac{(S_{11}) + (S_{21}) + G}{1 - (S_{11} + S_{21})G}$$

$$\frac{1}{\lambda_o} = \left(-\frac{1}{2\pi d}\ln\left(\frac{\lambda}{\lambda_c}\right)\right)^2$$

Finally, the complex permeability and permittivity of teflon can be formulated by

$$\mu = \frac{1 + G}{L(1 - G)\sqrt{\frac{\lambda^2}{\lambda_c^2} - 1}}$$

$$\varepsilon = \frac{\varepsilon_0}{\mu} \left(\frac{1}{\lambda_c^2} - \frac{1}{2\pi d}\ln\left(\frac{\lambda}{\lambda_c}\right)\right)^2$$

where $\Gamma$, $T$, $\lambda_o$, and $\lambda_c$ are reflection coefficient, transmission coefficient, free space and the cut off wavelength, respectively.

By using the equation (5) and (6), the complex permeability ($\mu$) and permittivity ($\varepsilon$) values can be calculated as shown in Fig. 3.
Figure 3. The complex permeability (a and b) and permittivity (c and d) values of teflon with thickness of 1.4 mm, 1.5 mm, and 1.6 mm in the mmWave band 50–67 GHz.

The complex permeability ($\mu = \mu' - j\mu''$) and permittivity ($\varepsilon = \varepsilon' - j\varepsilon''$) that were calculated by using the NRW method with the S-parameters ($S_{11}$ and $S_{21}$), which were simultaneously characterized by VNA. It is the well known that The real ($\mu'$ and $\varepsilon'$) and imaginary ($\mu''$ and $\varepsilon''$) parts reflect energy storage and dissipation, respectively [13–16]. The values of the $\mu'$ presents the trend of increases with increasing frequency and decreasing thickness. The increase in the $\mu'$ leads to decrease in the $\varepsilon'$ that the dominant contribution of magnetic energy storage come from this sample in the mmWave band 50–67 GHz. Meanwhile, both the $\varepsilon''$ and $\mu''$ were leading to strong fluctuations.

4 Conclusions
In summary, teflon with 1.4 mm, 1.5 mm, and 1.6 mm of thickness have been characterized by VNA and calculated by the NRW method to find the complex permeability and permittivity in the mmWave band 50–67 GHz. The increase in the $\mu'$ with decreasing thickness leads to decrease in the $\varepsilon'$ with increasing thickness. Both the $\varepsilon''$ and $\mu''$ show to strong fluctuations.

Acknowledgment
This work was financially supported by the Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT) 2021 (grant no. 281/E4.1/AK.04.PT/2021) of Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi, Republik Indonesia.

References
[1] W. Tian, R. Ma, J. Gu, Z. Wang, N. Ma, and P. Du. 2018, J. Mater. Chem. C. 6, pp. 12965–12975.
[2] C. Choi, K. Ko. 2010, Journal of Navigation and Port Research International Edition Vol. 34, pp. 111-115.
[3] F. C. Commission, N. Technology, and D. Division, “FEDERAL COMMUNICATIONS COMMISSION OFFICE OF ENGINEERING AND Millimeter Wave Propagation: Bulletin Number
70 July, 1997.

[4] J. S. Mccloy, K. Korolev, J. V Crum, and M. N. Afsar. 2013, IEEE TRANSACTIONS ON MAGNETICS, VOL. 49, NO. 1, JANUARY 2013, pp. 546–551.

[5] Maxim Zhadobov, Nacer Chahat, Ronan Sauleau, Catherine Quement and Yves Drean. 2011 International Journal of Microwave and Wireless Technologies, 3(2), 237–247, doi:10.1017/S1759078711000122.

[6] B. Zhao, B. Fan, G. Shao, W. Zhao, and R. Zhang. 2015, ACS Appl. Mater. Interfaces, 7, 18815–18823. DOI: 10.1021/acsami.5b05482.

[7] B. Zhao, B. Fan, Y. Xu, G. Shao, X. Wang, W. Zhao, and R. Zhang. 2015 “ACS Appl. Mater. Interfaces, 7, 26217–26225. DOI: 10.1021/acsami.5b08383.

[8] M.G. Vakhitov, D.S. Klygach, D.A. Vinnik, V.E. Zhivulin, N.S. Knyazev, 2019, J. Alloys Compd., 816, 152682. doi.org/10.1016/j.jallcom.2019.152682.

[9] J. Krupka, 2016, IEEE Microwave and Wireless Components Letters, vol. 26, no. 6, pp. 464–466, June, doi: 10.1109/LMWC.2016.2562640.

[10] E. Handoko, I. Sugihartono, and M. A. Marpaung, Maulana Randa, Mudrik Alaydrus and Nofrijon Sofyan. 2018, Materials Science Forum, 929, 109–115.

[11] E. Handoko, A. M. Mangasi, S. Iwan, M. Randa and M. Alaydrus. 2016, International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET), Jakarta, 2016, pp. 28-30, doi: 10.1109/ICRAMET.2016.7849576.

[12] E. Handoko et al 2018 J. Phys.: Conf. Ser. 1080 012002.

[13] X. Qiu and L. Wang. 2017, Nanoscale, 9, 7408-7418.

[14] Y.C. Qing · W.C. Zhou · S. Jia · F. Luo · D.M. Zhu. 2010, Appl Phys A (2010) 100: 1177–1181 DOI 10.1007/s00339-010-5738-5.

[15] Handoko, Erfan; Budi, Setia; Sugihartono, Iwan; Marpaung, Mangasi Alion; Jalil, Zulkarnain; Taufiq, Ahmad; Alaydrus, Mudrik. 2020, Materials Express, 10, pp. 1328-1336(9). DOI: https://doi.org/10.1166/mex.2020.1811.

[16] Chunhong Gong, Jiwei Zhang, Chao Yan, Xiaojian Cheng, Jingwei Zhang, Laigui Yu, Zhensheng Jin and Zhijun Zhang. 2012, J. Mater. Chem., 22, 3370.