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Experimental Analysis on Kapton Material using Peltier Thermoelectric De-vice

AH Dahalan[1,2],M. Z. A. Abd. Aziz[1], M.A. Othman[1], MS Amri[2]
[1]Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka;
[2]Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka;
abdulhalim@utem.edu.my, mohamadzoinol@utem.edu.my, azlishah@utem.edu.my, syahrin@utem.edu.my

ABSTRACT

Kapton is one of the flexible materials used in the develop-ment of microwave components for telecommunications system. The electrical properties of Kapton is dependent on the material's temperature. In this study, this material will be heated, and the electrical properties of dielectric permittivity and loss tangent will be analysed. This material heating pro-cess are done by using Peltier thermoelectric which are in-stalled with Aluminium alloy. The 0 V up to 7 V DC voltage were supplied to the Peltier during heating process. Then, the electrical properties of Kapton were measured by using die-lectric probe and vector network analyser (VNA) at frequen-cies of 1 GHz to 10 GHz. The results obtained show the Kap-ton temperature were increased from 25oC to 39oC. Mean-while, the dielectric permittivity also varied from 0.6 to 0.8 at the frequency of 5 GHz when 4 V voltage was used. The maximum loss tangent value of 0.5 was observed when the maximum DC voltage of 7 V was applied. The knowledge of this experimental work can be used to design reconfigurable microwave components for smart system application.

Key words : Kapton, Peltier thermoelectric, Dielectric.

1. INTRODUCTION

In telecommunication system, the application of flexible substrate is most popularly used in antenna design. One such material used is thin flexible polyimide substrate Kapton. Kapton is a material which is flexible and able to operate with very good flexibility over temperature ranging from (-73^{o}C to +400^{o}C)[1]. Kapton is a material which incorporates good mechanical properties, heat resistance, chemical resistance and electrical properties when compared with other materials. Comparison with other material are shown in Table 1 below;

Table 1: Comparison with Other Materials [1]

Material	PET	PEN	Kapton	LCP	Paper
Mechanical properties	Good	Good	Excellent	Good	-
Heat resistance	Low	Very good	Excellent	Good	-
Chemical resistance	Good	Good	Good	Excellent	-
Electrical properties	Good	Good	Good	Good	Good

Where,
PET - Polyethylene teraphthalate
PEN - Polyethylene naphthalate
LCP – Liquid crystal polymers

Previous studies by researchers employ many techniques or ways to heat materials such as, thermal chamber[2], chemical[3], induction heater[4], solar[5] , Peltier thermoelectric[6][7] etc. Thermal chamber [2] technique, where material will be heated through thermal chamber equipment will experience temperature value of 25^{o}C to 150^{o}C. Chemical[3] such as Magnesium (Mg)-based metal hydride system have potentially high temperature heat storage which covers a temperature range from 250^{o}C to 550^{o}C. Induction heater [4] also was applied to electric vehicles to generate heat by inputting electric power directly. Solar [5] also produced heat in the cooking system for families and institutions. It has two basic system components, solar collectors with reflectors and a cooking unit. Other researchers also applied Peltier for heat technique for food warmer and cooler with solar power [6]. Others designed heating and cooling jacket with microcontroller varying the temperatures from high to low depending on season[7].

Peltier thermoelectric is one of electronics product that can produced cooler or heater effect which is used in many applications such as refrigerator, air conditioner, power generation and etc [8]. In this experimental work, the heater side of Peltier were used to heat the material. The heat will be transferred to a conductive material such as Aluminium alloy. Aluminium is a good thermal conductor[9] in electrical and electronic design. Furthermore, the cost of Aluminium is cheaper when compared with copper.

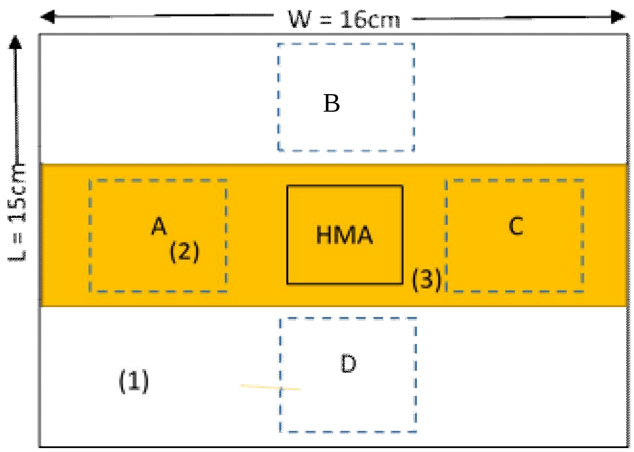
This paper will analyse the electrical properties of Kapton material which are dielectric permittivity (ε_r) and loss tangent at frequencies of 1 GHz up to 10 GHz. The heating process will use Peltier thermoelectric device with DC voltage from 0V to 7 V.

2. EXPERIMENTS DESIGN

2.1 Description of experiment Design

There are three main materials/components that have been used in this experimental work which are Kapton, Peltier thermoelectric and aluminium alloy plate. The Kapton material thickness is 0.055 mm. The thickness of the Aluminium alloy plate used is 0.2 mm. Four units of Peltier model TEC1-12706 with maximum temperature of 138 ^{o}C [10] were used. The experiment block setup is shown in Figure 1 and Figure 2.

The photos of in laboratory experimental setup are shown in Figure 3. There are three parts of study that will be done using this experimental setup. First, the correlation of DC voltage supply to Peltier and temperature of the Kapton will be formulated. Second, the analysis of the dielectric permittivity changes due to the temperature change on Kapton will be done for frequency of 1 GHz to 10 GHz. Third, the analysis of the tangent loss values due to temperature on Kapton will be measured for the frequency of 1 GHz to 10 GHz.



Note : *(1) Aluminium plate*
(2) Peltier (A,B,C & D - back side)
(3) Kapton
* HMA – Heat measured area

Figure 1: Experiment block design

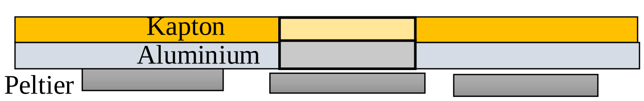
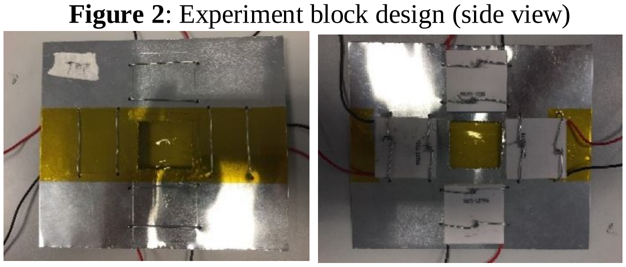


Figure 2: Experiment block design (side view)



(a) Top view (b) Bottom view

Figure 3: Photo of experimental setup

2.2 Experimental setup

The measurement equipment used in these experiment setups are DC power supply (30 V,2.5 A), Vector Network Analyzer (Agilent N5242A), Dielectric probe kit (Agilent 85070 E) and RMS multimeter (Agilent). All equipment is shown in Figure 4 below;

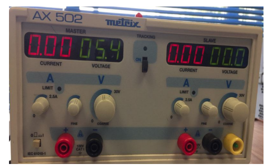
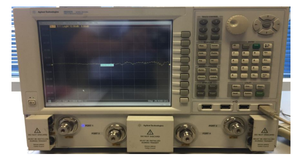
 DC Power Supply (i)	 Vector Network Analyzer (ii)
 Dielectric Probe Kit (iii)	 RMS Multimeter (iv)

Figure 4: Equipment used in experiment

The setup of experimental work is shown in Figure 5. Vector Network Analyzer (VNA) was calibrated first before being used for dielectric permittivity and loss tangent measurement. The frequency of measurement process was set starting from 1 GHz to 10 GHz. Then, the DC Power Supply was set to generate voltage from 0 V to 7 V. The increment of 0.5 V was adopted during the measurement process. In addition, the RMS Multimeter was used to measure the temperature of Kapton at heat measured area (HMA) The temperature, dielectric permittivity and loss tangent measurement result will be recorded based on voltage supply values. Every measurement process was repeated 5 times and the average values will be analysed and presented in the next session. A rest period between repeating processes is about 20 minutes, to ensure the temperature of the Peltier came back to room temperature.

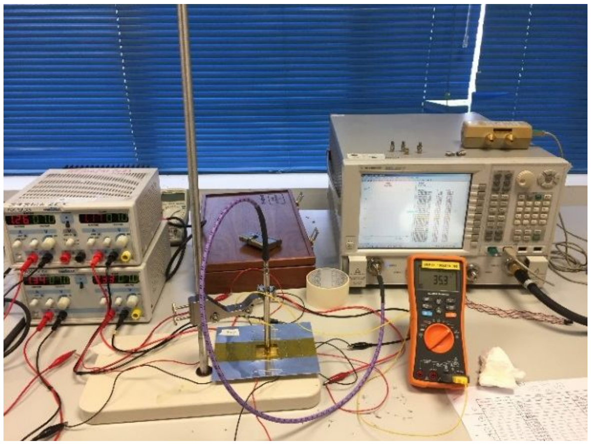


Figure 5: Equipment of experiment setup

3. EXPERIMENTAL RESULT AND DISCUSSION

3.1 Voltage and Temperature correlation

Experimental result of voltage and temperature correlation are shown in Figure 6. It is observed that, when the voltage was increased from 0 V to 7 V, the temperature of the Kapton also increased. The temperature of the Kapton was increased from 25°C to 39°C. Based on the experimental result, the Peltier device will start producing the heater effect when the DC voltage was supplied. Four Peltiers were arranged in top, down, right and left sides to ensure the heating process are uniform and equal towards HMA area.

Referring to Figure 1, HMA points as shown in Figure 7. There are 9 points of HMA has been identified and noted as *a* to *i*. Referring to Figure 1, the design starts with single, dual, triple and quad Peltiers. The configuration design for Peltiers are shown in Table 2 as below;

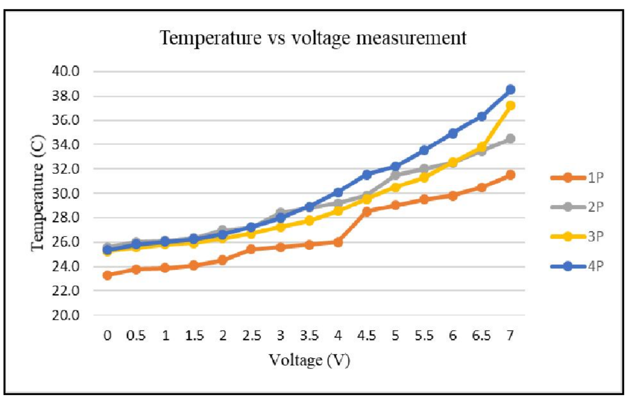


Figure 6: Temperature and voltage correlation

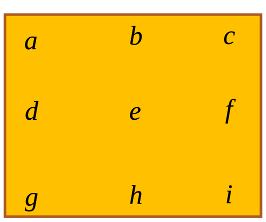


Figure 7: 9-point measurement of HMA

Table 2: Configuration Design for Peltier

Peltier (P)	Configuration Design
Single	A
Double	A+C
Triple	A+B+C
Quad	A+B+C+D

Table 3: HMA result

	Temperature (°C)								
P	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*I*
1	33.3	32.5	31.2	33.6	31.5	30.1	40.3	32.5	33.0
2	47.5	45.5	46.0	38.5	34.5	45.1	52.5	42.5	46.5
3	53.3	52.7	51.8	53.5	40.5	44.2	60.7	44.0	46.5
4	54.5	55.5	53.5	53	47.5	52.5	53.2	51.3	53.5

*P = No of Peltier used

The result shows the different of temperature being measured at 9 points of HMA when only one, two or three Peltier were used. However, the heating process is more uniform and equal when 4 Peltier were used.

3.2 Dielectric Effect on Temperature

Kapton is a thin flexible polymide substrate where the material has relative permittivity (ε_r) and loss tangent ($tan\ \delta$). The dielectric permittivity of Kapton value changes according to the temperature range of (-73°C to +400°C). Therefore, when the voltage supplied to the Peltier and Aluminium plate started heating, Kapton will be affected due to the temperature change. When this happens, dielectric characteristic also will be affected. The experiments result is shown in Figure 8. When the voltage increased is from 0 V to 7 V, the dielectric value was increased. For example, at voltage 4 V, dielectric increased from 0.6 to 0.8. At higher frequency, the value of dielectric is also higher. Similarly at lower frequency, the value of the dielectric is also lower.

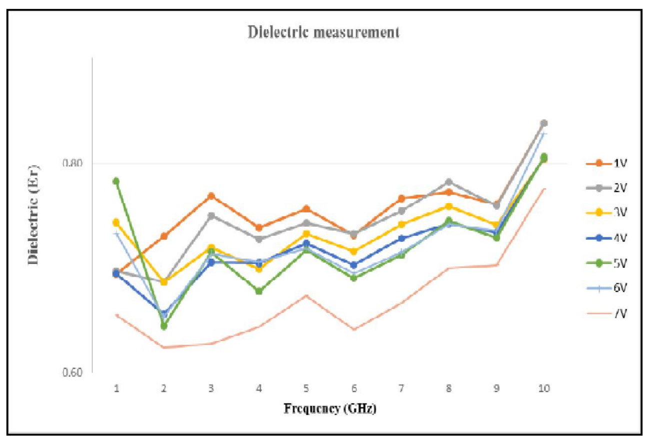


Figure 8: Dielectric measurement (Dielectric vs Frequency)

The dielectric value also reduces when the voltage supply is high. Figure 9 shows, dielectric value is high with low temperature compared with high temperature. For example, at frequency 5 GHz, dielectric decreases from 0.73 to 0.67.

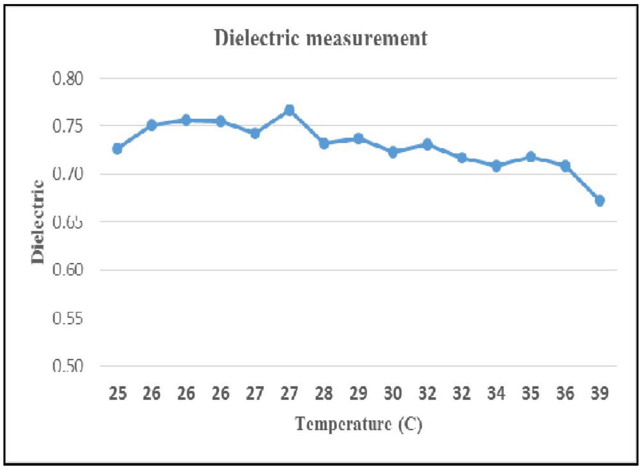


Figure 9 : Dielectric measurement
(Dielectric Vs Temperature)

3.3 Loss Tangent Effect on Temperature

In dielectric material analysis, loss tangent is an important parameter which will present the electrical losses of the material. From the graph in Figure 10 it can be seen that the loss tangent is very low where the value is below 0.5. For lower frequency, the value of loss tangent is higher compared to higher frequency. When the voltage was increased from 0 V to 7 V, the loss tangent value was reduced. For example, at voltage of 4 V, the loss tangent reduces from 0.26 to -0.27.

Loss tangent value also reduces when the voltage supply given is high. Figure 11 show, loss tangent value is high with low voltage input compared to high voltage. For example, at the frequency of 5 GHz, the loss tangent reduces from -0.13 to -0.25.

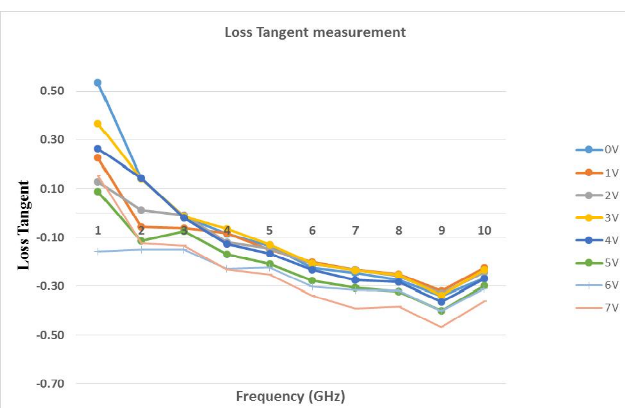


Figure 10 : Loss Tangent measurement
(Loss Tangent Vs Frequency)

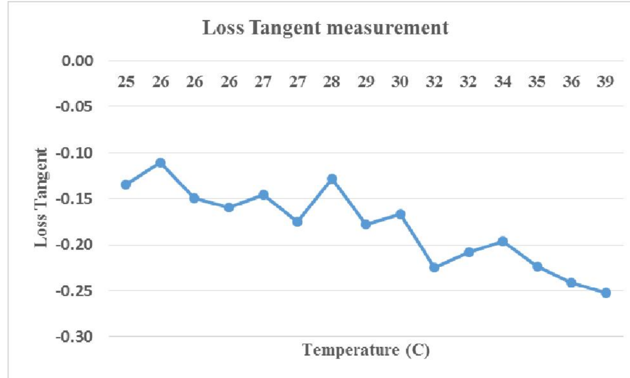


Figure 11 : Loss Tangent measurement
(Loss Tangent vs Temperature)

4. CONCLUSION

In this paper, the dielectric permittivity and loss tangent of Kapton was changed when the temperature of the material increased. Four Peltier were used to ensure the heating process of Kapton is uniform. The difference of 0.2 can be observed when the voltage supply is increased from 1 V to 7 V. The 0.2 difference of loss tangent value was also recorded when similar voltage supply was applied. These change characteristics can be used to design microwave component such as antennas or filters for smart systems application.

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