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Experimental Analysis on Double Layer Kapton Material using Peltier Thermoelectric Device

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ABSTRACT

Kapton is one of the flexible materials used in the development of microwave components for the telecommunications system. The electrical properties of Kapton are 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 analyzed. This material heating process is done by using Peltier thermoelectric which is installed with Aluminium alloy. The 0 V up to 7 V DC voltage was supplied to the Peltier during the heating process. Then, the electrical properties of Kapton were measured by using a dielectric probe and vector network analyzer (VNA) at frequencies of 1 GHz to 9 GHz. The results obtained show the Kapton temperature was increased from 27°C to 41°C. Meanwhile, the dielectric permittivity also varied from 1.72 to 1.64 at the frequency of 5 GHz when 4 V 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 applications

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1. INTRODUCTION

In a 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 that is flexible and able to operate with very good flexibility over-temperature ranging from (-73°C to +400°C)[1]. Kapton is a material that 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 terephthalate
PEN - Polyethylene naphthalate
LCP – Liquid crystal polymers

There are many techniques to heat materials such as thermal chamber [2], chemical [3], induction heater [4], solar [5], Peltier thermoelectric [6][7] has been reported. Thermal chamber [2] technique, where the material will be heated through thermal chamber equipment with a temperature value of 25ºC to 150ºC. Chemical technique [3] such as Magnesium (Mg)-based metal hydride system has potentially high-temperature heat storage which covers a temperature range from 250ºC to 550ºC. The 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 produce cooler or heater effect which is used in many applications such as refrigerator, air conditioner, power generation, etc [8]. In this experimental work, the heater side of Peltier was used to heat the material. The heat will be transferred to a conductive plate material such as Aluminium alloy. Aluminum is a good thermal conductor [9] in electrical and electronic design. Furthermore, the cost of Aluminium is cheaper when compared to copper material.

This paper will analyze the electrical properties of Kapton material such as dielectric permittivity (ε_r) and loss tangent at frequencies of 1 GHz up to 9 GHz. The heating process will use the Peltier thermoelectric device with a DC voltage from 0V to 7 V.

2. RESEARCH METHOD

2.1 Description of experiment Design

There are three materials have been used in this design work which is Kapton, Peltier thermoelectric and aluminum alloy plate. The Kapton and Aluminum alloy material thickness are 0.055 mm and 0.2 mm respectively. The heating process was done by using the Peltier thermoelectric model TEC1-12706 with a maximum temperature of 138 ºC [10]. The experiment block design is shown in Figure 1 and Figure 2.

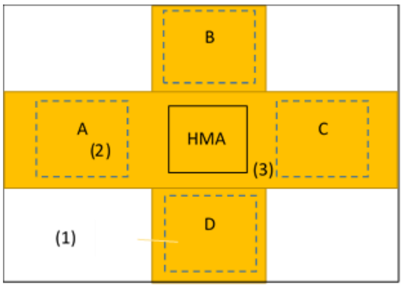

Figure 1. Experiment block design

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

* HMA – Heat measured area

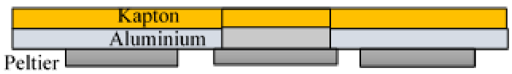

Figure 2. Experiment block design (side view)

The photo of prototype experimental design as shown in figure 3, where (a) is a front side view and (b) is a backside view.

(a) (b)

Figure 3. Photo of prototype experimental design

There are three main analyses will be done based on this experimental work. First, the analysis of the correlation of temperature and applied DC voltage will be formulated. Secondly, the analysis of the dielectric changes on Kapton will be studied. This is due to the dielectric of the Kapton will be the effect when the temperature increases or decreases. Third, the analysis of the loss tangent versus temperature of the system will also be done.

2.2 Experiment equipment's setup

The types of equipment used in the experiment are (i) DC power supply (30V,2.5A), (ii) PNA-L Network Analyzer (Keysight N5232A), (iii) Dielectric probe kit (Agilent 85070 E) and (iv) RMS multimeter (Agilent).

All types of equipment are connected as shown in Figure 4. The calibration of the Network Analyzer will be performed first before the dielectric measurement been done. Then, the start and stop frequency of the Network Analyzer were set to 1GHz up to 10GHz. While DC Voltage of 0V to 7V was set as the input voltage to the Peltier with a 0.5V voltage increment. During the measurement process, the parameter of temperature, dielectric permittivity and tangent loss of the Kapton will be recorded. The measurement process was repeated 5 times to obtain accurate measured data. The temperature of the Peltier was set to room temperature before each measurement process started. This process was done by adopted 20 minutes of relaxing time right after every measurement process.

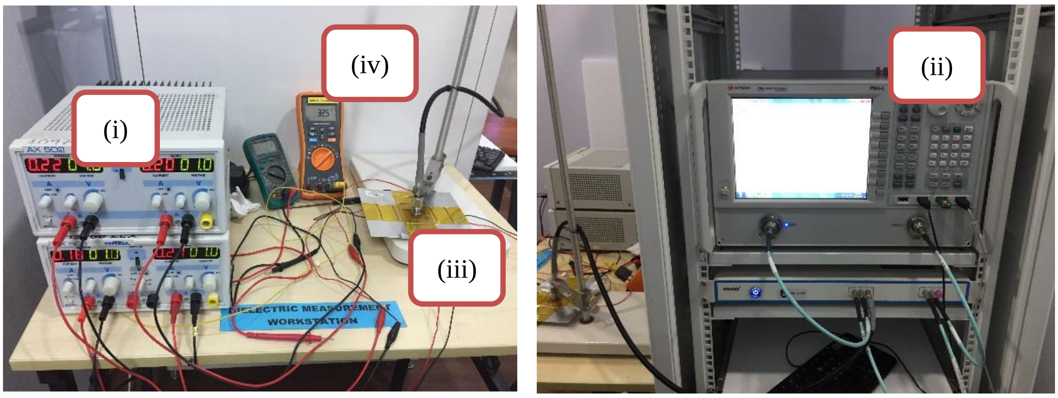

Figure 4. Equipment's experiment setup

3. RESULTS AND ANALYSIS

3.1 Voltage and Temperature correlation

The experiment result for voltage and temperature correlation is shown in Figure 5. The temperature was increased from 27ºC to 41ºC as the voltage increased from 0V to 7V. When the voltage was supplied to the Peltier device, the heat will be produced and the temperature of the Kapton was increased. The higher heating temperature was achieved by using four-unit of Peltier.

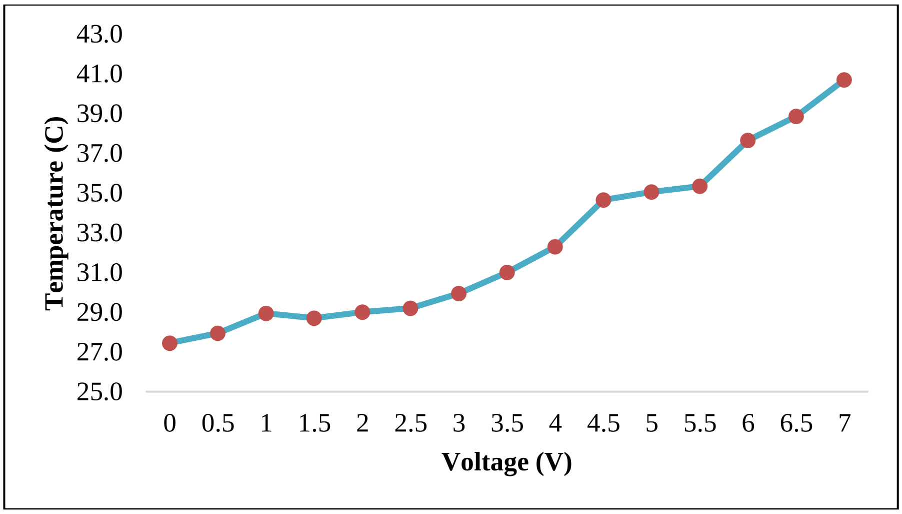

Figure 5. Voltage and Temperature correlation

3.2 Dielectric permittivity effect

Kapton is a thin flexible polyimide substrate where the material has relative dielectric 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, the temperature of Kapton increased when the DC voltage supplied to the Peltier and Aluminium plate increased. At this stage, the dielectric permittivity of the Kapton also will be affected. The experiments result of dielectric permittivity versus frequency for Kapton is shown in Figure 6. When the voltage increased is from 0 V to 7 V, the dielectric value was decreased from 1.38 to 0.20. At a higher frequency of 9 GHz, the value of dielectric permittivity measured around 0.20 to 0.29. While the dielectric permittivity value of 1.38 to 1.58 was measured at a frequency of 1 GHz.

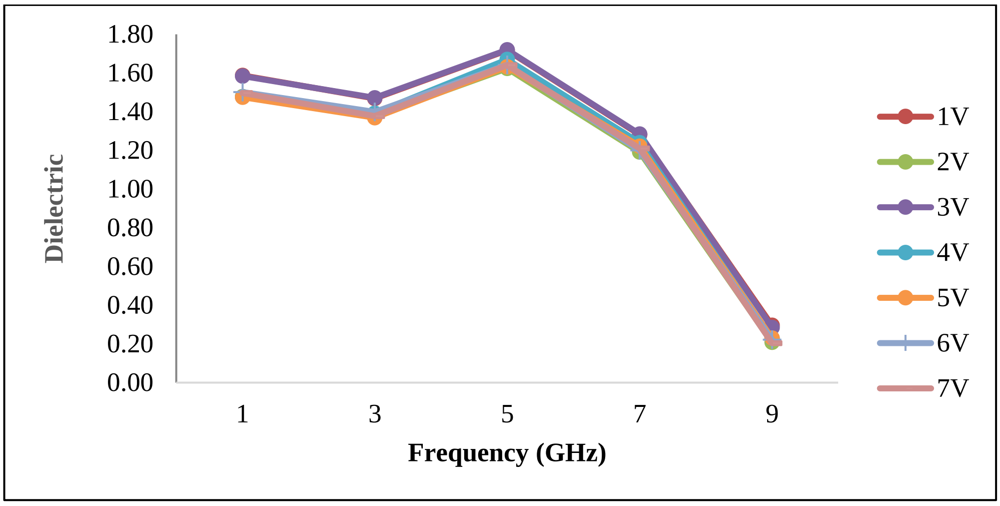

Figure 6. Dielectric permittivity versus frequency

The dielectric permittivity value also decreased when the DC voltage supply is increased. Figure 7 shows the dielectric permittivity value versus temperature of the Kapton. There is a small drop of dielectric permittivity value found at the temperature of 29^0C for every frequency. Then, the dielectric permittivity value was increase between 1.285 up to 1.720 for the temperature of 30^0C. The highest dielectric permittivity was measured between 1.720 to 1.641 at the frequency of 5 GHz. While the lowest dielectric permittivity value was measured between 1.285 to 1.194 at the frequency of 7 GHz. The measurement result shows that the dielectric permittivity value is reduced as the frequency increased except for the frequency of 5 GHz.

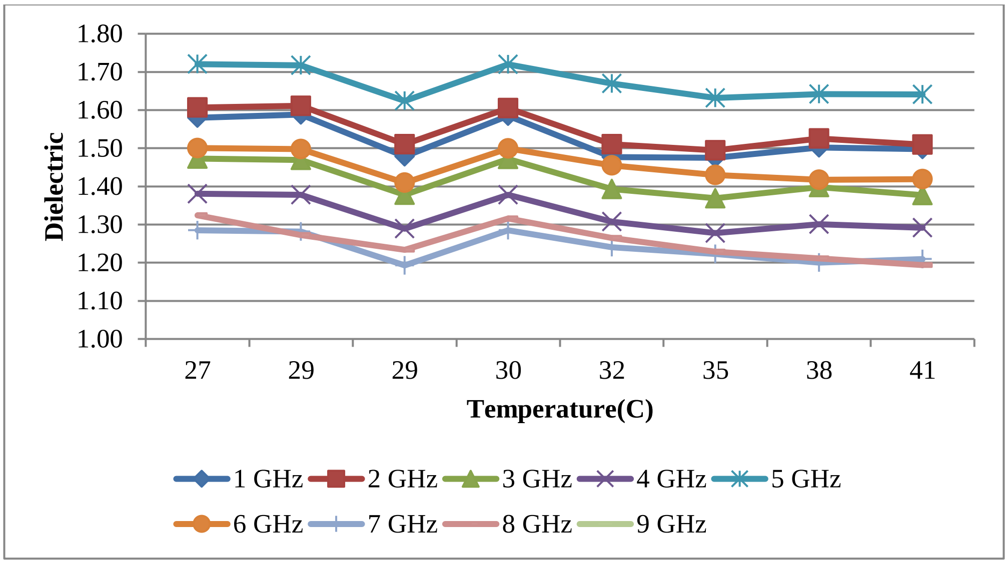

Figure 7. Dielectric permittivity versus temperature

3.3 Loss tangent effect

The loss tangent is an important parameter that will present the electrical losses of the material. Figure 8 shows the loss tangent of Kapton versus frequency. The result shows that the loss tangent of the Kapton is lower than 0.5. The loss tangent value is increased from 0.03 at frequency 1 GHz up to 0.48 at a frequency of 9 GHz. There is an increment of 0.17 can be seen at frequency 9 GHz when the DC voltage is increased from 1 v to 7 V. While, the increment of 0.16 can be seen at frequency 5 GHz for all DC voltage values.

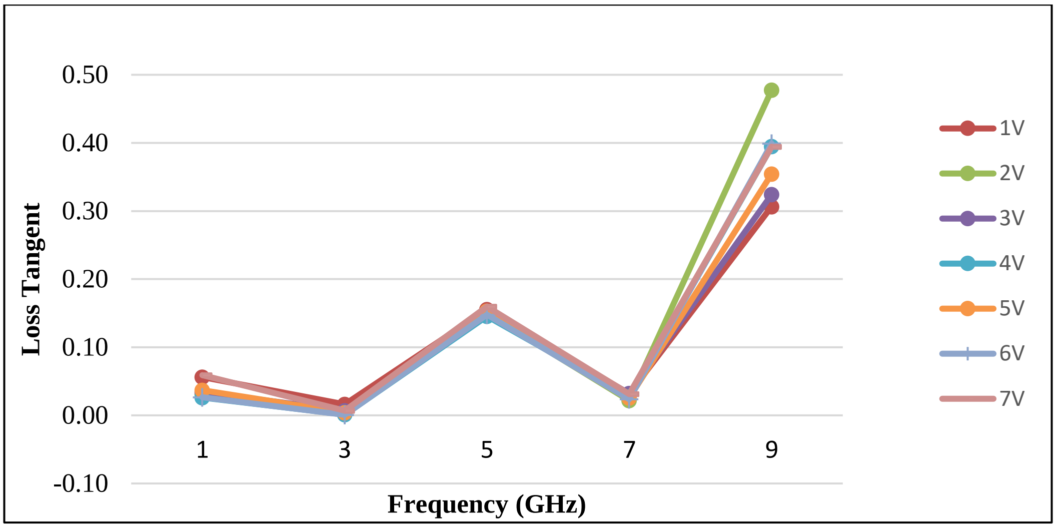

Figure 8. Loss Tangent versus frequency

Loss tangent value also increases when the DC voltage supply is given is increased. Figures 9 and 10 show the loss tangent versus temperature of Kapton. The loss tangent of Kapton at a frequency of 5 GHz shows a small increment from 0.145 to 0.16 for the temperature of 27 °C to 41 °C. While the small increment of 0.021was also found for frequency 8 GHz. The highest value of loss tangent is 0.478 was measured at frequency 9 GHz and temperature of 29^{0}C.

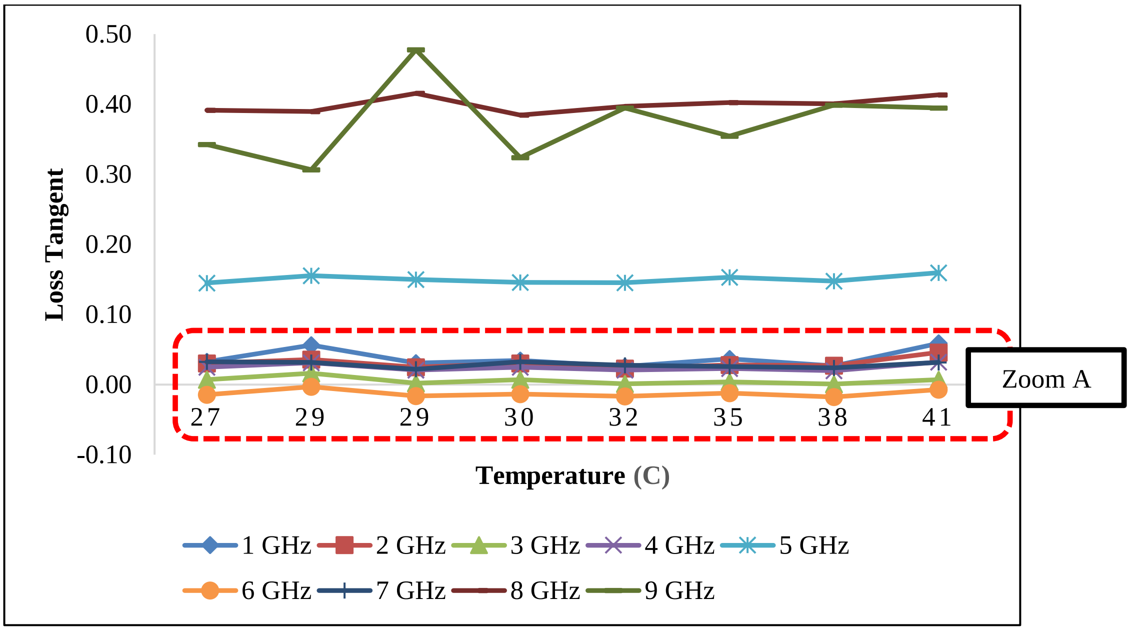

Figure 9. Loss Tangent versus temperature

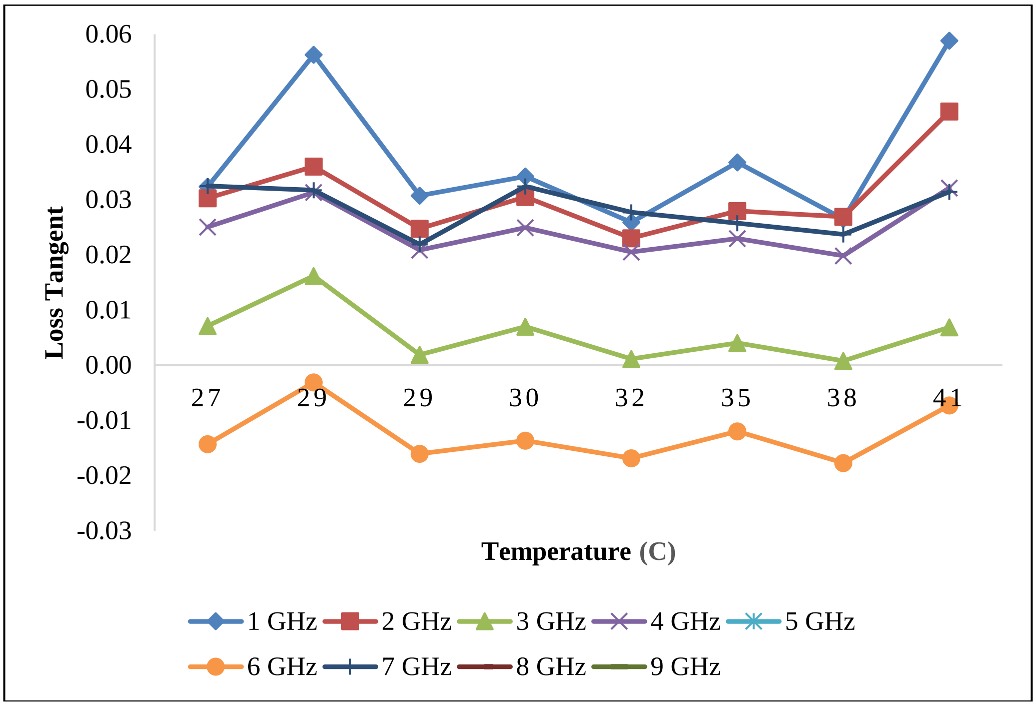

Figure 10. Loss Tangent versus temperature (Zoom A)

The loss tangent of other frequency was measured less than 0.06 towards all temperature values. The loss tangent for these frequency groups are found between -0.018 up to 0.06. The graph for frequency 3 GHz shows the tangent loss is close to 0. While the graph for frequency 6 GHz shows the loss tangent value lower than zero.

4. CONCLUSION

In this paper, the dielectric permittivity and loss tangent of Kapton was changed when the temperature of the material increased. Four units of Peltier were used to ensure the heating process of Kapton is uniform. The difference of 0.15 can be observed when the DC voltage supply is increased from 1 V to 7 V. The 0.2 difference of loss tangent value was also recorded when a similar DC voltage supply was applied. These change characteristics can be used to design microwave components such as antennas or filters for smart systems applications.

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