CHAPTER 2

THEORY AND LITERATURE REVIEWS

This chapter review the fundamental of thermoelectric theory, history of thermoelectric effect, dimensionless figure of merit (*ZT*), thermoelectric properties of Bi_2Te_3, principle and working of thermocouple, Arduino and Wi-Fi module ESP8226. The performance of thermoelectric material is described by three related mechanisms: the Seebeck coefficient, electrical conductivity and thermal conductivity. The Bi_2Te_3 system section reviews topics on synthesis method, thermoelectric properties and temperature sensor of Bi_2Te_3

THERMOELECTRIC EFFECT

Thermoelectric effect provides the direct the conversion of heat energy into electrical energy, or vice versa in the thermoelectric device. The effect is governed by 3 related mechanisms: the Seebeck effect, the Peltier effect and Thomson effect. (David Michael Rowe, 2005)

Seebeck Effect

In 1821, Thomas Johnson Seebeck, German Physicist, (1770-1831) discovered that “When the junctions of two different metals are maintained at a different temperature, electric current would flow continuously in a closed circuit”, as shown in Figure 2.1 (T. Seetawan, 2015).

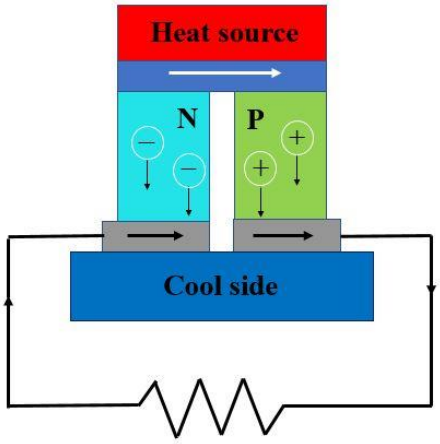

Figure 1 Seebeck effect

Seebeck effect is to the phenomena heat transfer into electricity. The physical significance is determined by the phenomenon of a constant temperature gradient. Initially, the conductor controls the uniform distribution of charge carriers, under temperature gradients. The carriers were heated end is more kinetic than the cold end and tends to spread to the cold end. The formation of the charge causes the electric current to reverse, which is the opposite of the charge flow. The open circuit voltage, when there is no current, is called the Seebeck voltage. Equation of the Seebeck coefficient, if written in the form of difference in electric potential and temperature effect, is that

$$-\frac{dV}{dx} = S\frac{dT}{dx}$$

$$-\Delta V = S\Delta T$$

$$S = -\frac{\Delta V}{\Delta T} \tag{2.1}$$

where

S is Seebeck coefficient (V K^{-1})

ΔV is Voltage difference (V)

ΔT is Temperature difference (K)

A material has Seebeck coefficient, not equal to zero is thermoelectric materials. The positive and negative Seebeck coefficient depend on the properties of the material. In the case of the *n*-type semiconductor, the Seebeck coefficient of behavior is negative, but the *p*-type semiconductor has a positive.

Peltier Effect

In 1834, Jean Charles Athase Peltier, French Physicist, (1785-1845) discovered that "When the electric current flows are heated, the conductor is heating. The heat will increase or decrease depending on the flow direction of the electricity", as shown in Figure 2.2 (T. Seetawan, 2015, P. Kovitcharoenkul, 2007)

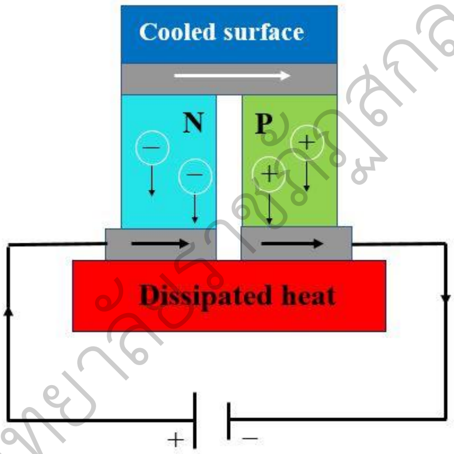

Figure 2 Peltier Effect

The Peltier phenomenon is a phenomenon which is coupled with the Seebeck effect. It was used to make the cooling system from change electric to system cooling (thermoelectric refrigeration).

$$\dot{Q} = \frac{dQ}{dt} = (\Pi_A - \Pi_B)I \qquad (2.2)$$

where

$\dot{Q}$ is the return heat absorption rate (W)

Π_A is the Peltier coefficient of the conductor A. (W A^{-1})

Π_B is the Peltier coefficient of the conductor B. (W A^{-1})

I . Is the current supplied from conductor A to B (A)

The relationship between the Seebeck phenomenon and the Peltier phenomenon can be written as Equation.

$$\Pi = ST \tag{2.3}$$

Thomson Effect

In 1954, William Thomson (Lord Kelvin), Scotland Physicist discovered that "when an electricity through two conductors at different temperature. The direction of heat depends on the flow of electricity from the cold spot to the hot spot, or from hot spots to cold spots" (T. Seetawan, 2015).

Thomson phenomenon is a phenomenon related to the rate of return of heat $\Delta Q = Q_h - Q_c$. Due to the passage of electric current along the single conductor at different temperature $\Delta T = T_h - T_c$

DIMENSIONLESS FIGURE OF MERIT

Dimensionless figure of merit (ZT) is the equation that indicates the performance of thermoelectric materials. The performance of thermoelectric materials is related to a parameter called the dimensionless figure of merit is given by

$$ZT = \frac{S^2 T}{\rho \kappa} \tag{2.4}$$

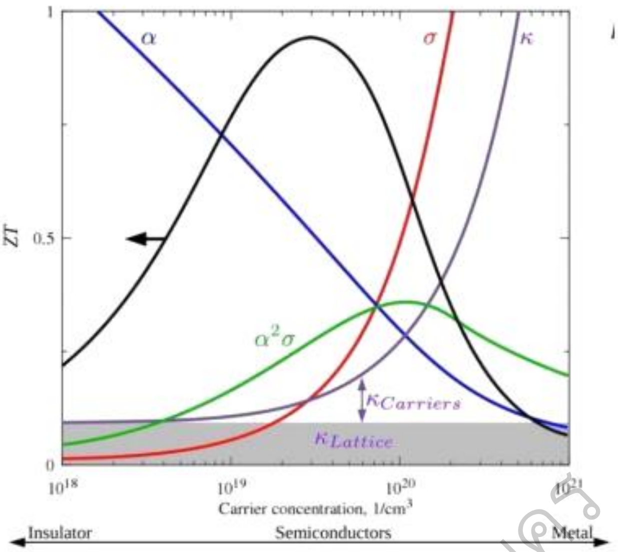

Figure 3 The relationship between carrier concentration with ZT.

where

ZT	is Dimensionless Figure of Merit
S	is Seebeck coefficient
ρ	is electrical resistivity
κ	is thermal conductivity
T	is temperature

THERMOELECTRIC MATERIALS

Thermoelectric materials p-type

Thermoelectric materials, p-type is a hole or has a positive charge. The outer electrons of each atom were exchanged electrons with each other or used electrons together. In this case, one electron is missing cause gap of electron, this gap is called Hole. When there is a difference in temperature, the material will cause hole was a movement to electric discharge. (T. Seetawan, 2015)

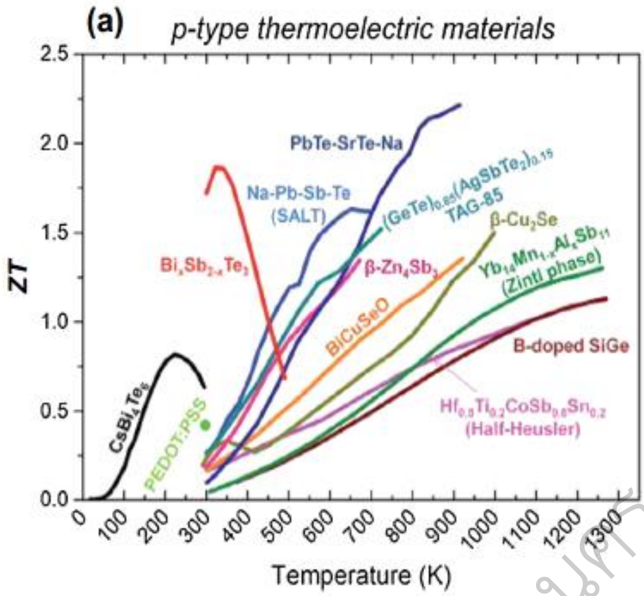

Figure 4 Summary of the temperature dependence of ZT of thermoelectric p–type materials (Dinesh K. Aswal, Ranita Basu, & Ajay Singh, 2016)

Thermoelectric materials n–type

Thermoelectric materials, n- type is an electron or has a negative charge. The outer electrons of each atom were exchanged electrons with each other or used electrons together. In this case, one electron has still remained and can't handle with neighboring atom, this electron is called electron free. When there is a difference in temperature, the material will cause electron free was a movement to electric discharge. (T. Seetawan, 2015)

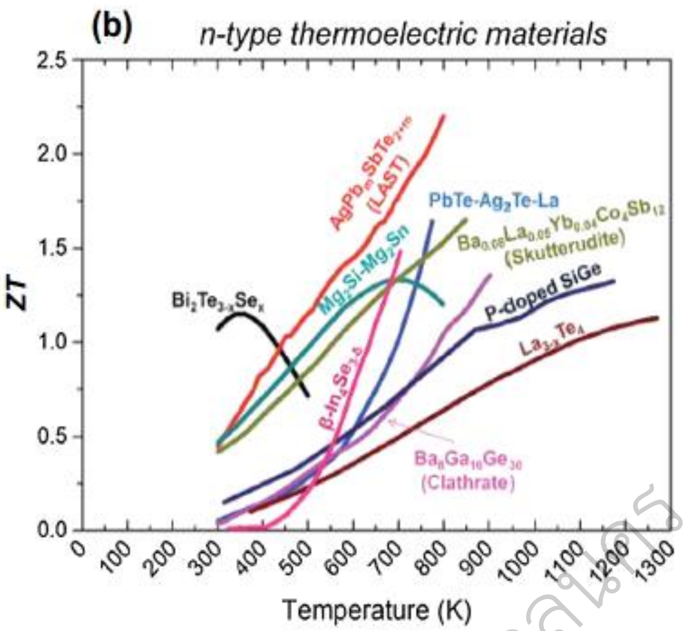

Figure 5 Summary of the temperature dependence ofZTof thermoelectric n- type materials (Dinesh K. Aswal, Ranita Basu, & Ajay Singh, 2016)

BISMUTH TELLURIDE

Bismuth Telluride (Bi_2Te_3 materials) discussed as high-performance thermoelectric properties, because the Bi_2Te_3 is a small band gaps lead to high Seebeck coefficient, electrical conductivity and thermal conductivity is very low, a maximum ZT value of 0.75 at 300 K (Kim H, Han M-K, & Kim S-J, 2012). Thus, Bi_2Te_3 is to one of the best thermoelectric materials since it has a capability to convert waste heat energy into the beneficial electrical energy (Culebras M, Uriol B, Gómez & CM, Cantarero, 2015). In recent years, many studies have been carried out to obtain high efficiency thermoelectric materials through the development of Bi_2Te_3 (Antonenko AO, Charnaya EV, & Marchenkov YV, 2017, Luo B, Deng Y, & García-Cañadas J, 2016). Bi_2Te_3 is a material from the group of space group 166 and lattice parameter $a = b = 4.38$ Å and $c = 30.48$ Å (Guo W, Ma J, & Zheng W 2016). Bi-Te is a compound of bismuth (Bi) and tellurium (Te), with composition Bi_2Te_3 show in Figure 6.

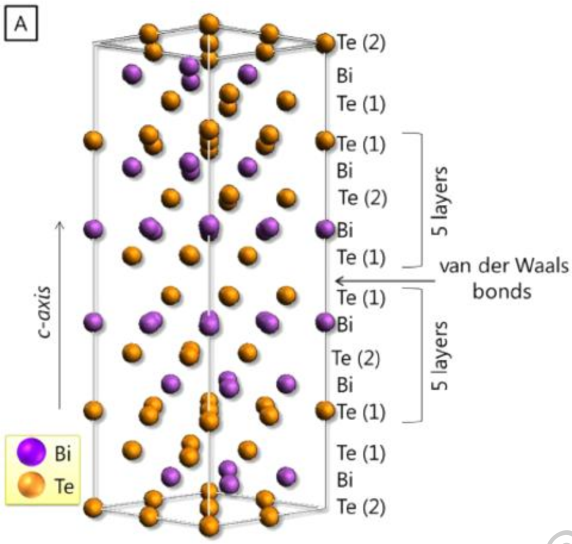

Figure 6 The crystalline of bismuth telluride (Bi_2Te_3) (Cristina V. Manzano, Begoña Abad, & Marisol Martin-Gonzalez, 2015)

Bi physically behaver like a metal and atomic number 83. But when it is alloyed with Te, then it behaver like an efficient semiconductor thermoelectric type material. The melting point and transition temperature of the materials increases, crystallization speed decreases and data retention increase, the melting point of Bi_2Te_3 materials is 580 ^{o}C (1,076 ^{o}F; 853 K) (Haynes and William M, 2011). The crystalline of Bi_2Te_3 has two possible configurations: hexagonal and trigonal (Guo W, Ma J, Zheng W, 2016). Bi_2Te_3 has transition temperature of around < 25 ^{o}C a maximum ZT value of 0.8 at 48 ^{o}C (Chung D-Y, Hogan T & Bastea M, 2000), when it is doped antimony (Sb) then it behaves like a semiconductor p-type a maximum ZT value 1.86 at 47 ^{o}C (Jiang Q, Yan H, & Simpson, 2014) and selenium (Se) alloy then it behaves like a semiconductor p-type a maximum ZT value 1.15 at 97 ^{o}C (Hu L-P, Zhu T-J, & Zhao X-B, 2014). It can be used for some applications like as thermoelectric refrigeration, TEG, TEC and thermal sensor (Gaikwad M, Shevade D, & Kadam A, 2016).

THERMOELECTRIC MATERIALS EFFICIENCY

The Research and development of semiconductor thermoelectric materials, found that the good performance of thermoelectric materials, it must have the following features.

1. The heat of the thermoelectric materials must be dissipated, or transport with as much electricity, which is high Seebeck coefficient

2. The thermoelectric materials has low electrical resistivity, it good for electrical conductivity, Otherwise, the electricity will lose and turn back to heat.

3. The thermoelectric materials are the low conductor of the heat; the direction reverses the direction of charge. Due to photons move on the heat, the direction reverses of electric charge. As a result, the performance of thermoelectric materials decreased.

The three properties are related by the principle of physics based on the equation (2.4) (T. Seetawan, 2013).

Since Z (figure of merit) a unit per temperature, the comparative value should be no unit. T will be multiplied by Equation (2.4), the new equation is ZT (dimensionless figure of merit) by T is temperature. The ZT is indicative properties of change heat to the maximum electrical energy. The performance in the theory of modules can be obtained from the equation (2.5) (Fergure, J.W., 2012).

$$\varepsilon = \frac{T_h - T_c}{T_h}\left[\frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}-\left(\frac{T_c}{T_h}\right)}\right] \qquad (2.5)$$

where

ε is the performance of thermoelectric materials

T_h is the hot temperature (K)

T_c is the cold temperature (K)

ZT is Dimensionless Figure of Merit

THERMOELECTRIC CELL AND MODULE EFFICIENCY

The efficiency of power diversion for thermoelectric module can be obtained from equation (2.6).

$$\eta = \frac{W}{Q_H} = \frac{I\left[\left(S_p - S_n\right)\Delta T - IR\right]}{K\Delta T + \left(S_p - S_n\right)IT_H - \frac{1}{2}I^2R} \tag{2.6}$$

where

η is the performance of thermoelectric module

W is the electrical energy from thermoelectric module

Q_H is the thermal energy provided by thermoelectric module

I is electrical

R is the total electrical resistance of *p-type* and *n-type* based on equation (2.7)

$$R = \frac{L_p\rho_p}{A_p} + \frac{L_n\rho_n}{A_n} \tag{2.7}$$

where

L is the length of substance

ρ is the electrical resistance

A is cross-sectional area of substance

K is the total of thermal conductivity for p-type and n-type based on equation (2.8).

$$K = \frac{\kappa_p A_p}{L_p} + \frac{\kappa_n A_n}{L_p} \qquad (2.8)$$

where

κ is thermal conductivity

S is Seebeck coefficient

T is temperature

p and n is p-type and n-type respectively

THERMOCOUPLE SENSOR

The thermocouple is a device used to measured temperature or heat as electric power (emf). Thermocouples are made of two different metal conductors (different atomic structure) were connect the two ends together at one end, called a temperature point. The other end is closed, called a reference point. The temperature point and reference point have a different temperature that will to a current flow in the thermocouple circuit.

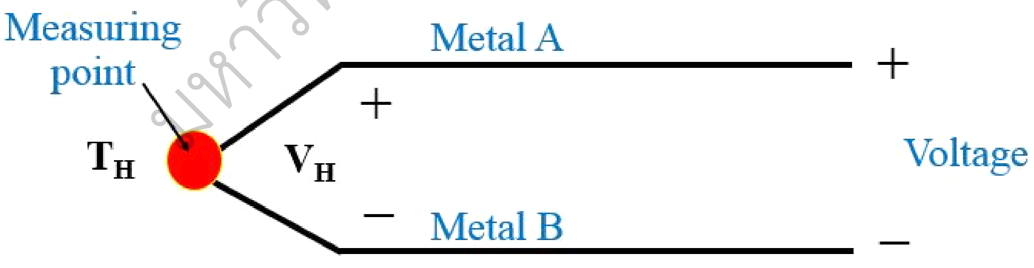

Figure 7 Show the connection of metal A and B wire of thermocouple.

Effect of Thermocouple Voltages

The basic theory of thermoelectric effect consists the transmission of electricity and heat of a different metal, As a result, electric potential difference in metal. The electron in the hot end of the metal has thermal power more than a cold end. The electron was traveling to the cold at the same temperature, the movement of electron was changed with the different metals. Due to the different metals, have differential thermal conductivity. The Seebeck effect by solid state theory. It can be calculated from the integral equation of the temperature,

$$\varepsilon = \int_{T_1}^{T_2} (Q_A - Q_B) dT \qquad (2.9)$$

This equation describes the effect of Seebeck.

1. The resulting emf is proportional to the difference in temperature. The difference in the heat transfer coefficient of the metal.

2. If the same metal is used for thermocouple, the emf value is zero.

3. If both temperatures are the same temperature point and reference point, the emf value was zero. The simple formula is also computable.

$$e = S(T_2 - T_1) \qquad (2.10)$$

where

S is Seebeck coefficient (V K^{-1})

T_1, T_2 is Temperature (K)

Reference Junction

In general, the thermocouple is used to measure the temperature. The copper wire was connected to the reference junction to measure the electrical force. The connection between the metal were increased by 2 points. As a result, the voltage is changed. If the temperature at the point connected to both copper lines is the same temperature, the voltage from these two points was offset. The measurement of electric power, not effect. Therefore, it is necessary to maintain these two points to the same value, call this point Isothermal Block (Temperature Hand Book, 2016).

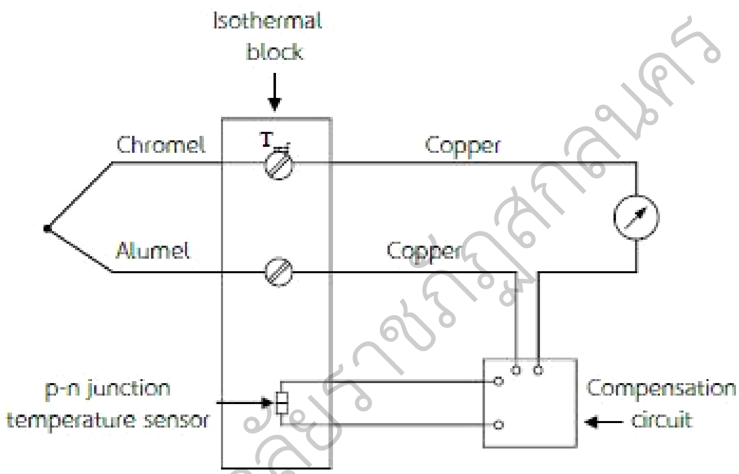

Figure 8 Show the basic circuit for temperature measurement using thermocouple

STANDARD OF THERMOCOUPLE

Sensitivity

From the Table 1 shown the force of the thermocouple is less than 100 mV. However, the actual sensitivity of the application depends on the signal conditioning circuit and the thermocouple itself.

Construction

The structure of the thermocouple must have the following characterization: low resistance, high performance in high temperature, resistant to high temperature oxides and resistant to the environment. The most of them are made of stainless steel.

Application Area

The operating temperature and sensitivity of each thermocouple are different. The most importantly, the force from each temperature based on the standard table.

Time Response

The thermocouple response time depends on the size of wire and the material used to make the thermocouple hose.

Signal Conditioning

Normally, the thermocouple was power is very small, so amplifiers are required using op-amp amplifiers.

Table 1 The energy consumption of thermocouple

Type of Wire (USA and Canada color)	**Temperature Rang**	**Limits of Error (Select whichever is greater)**	
		Standard Grade	**Premium Grade**
Type T Copper–Constantan	-200 to 0 °C 0 to 350 °C	±1 °C or ±1.5% ±1 °C or ±0.75%	--- ±0.5 °C or ±0.4%
	-300 to 32 °F 32 to 1400 °F	±1.5 °F or ±2% ±1.5 °F or ±0.75%	±0.75 °F or ±1% ±0.75 °F or ± 0.38%
Type J Iron–Constantan	0 to 750 °C 32 to 1400 °F	±2.2 °C or ±0.5% ±4 °F or ±0.5%	±1.1 °C or ±0.4% ±2 °F or ±0.38%
Type E Chromel–Constantan	0 to 900 °C 32 to 1600 °F	±1.7 °C or ±0.5% ±3 °F or ±0.5%	±1 °C or ±0.4% ±2 °F or ±0.38%
Type K Chromel–Alumel	0 to 1250 °C 32 to 2300 °F	±2.2 °C or ± 0.75% ±4 °F or ±0.75%	±1.1 °C or ±0.4% ±2 °F or ±0.38%
Type R or S Platium–Rhodium/Platinum	0 to 1450 °C 32 to 2700 °F	±1.5 °C or ± 0.25% ±3 °F or ±0.25%	--- ---
Type B Platinum 30% Rhodium/ Platinum 6% Rhodium	800 to 1700 °C 1600 to 3100 °F	±0.5% ±0.5%	--- ---

Thermocouple T (copper/constantan)

The output of this type can be determined as a function of temperature in table 1. The thermocouple T is used to generate exact values of voltage as a function of temperature from 0 $^{\circ}$C to 350 $^{\circ}$C. The inverse relation, for temperature as a function of voltage, is generated at the same temperature.

Thermocouple J (iron/ constantan).

The output of this type can be determined as a function of temperature in Table 1. The resulting values are exact by definition. This shows the inverse relation for temperature as a function of voltage over the same temperature range. For type J, temperature as given to 0 $^{\circ}$C to 750 $^{\circ}$C

Thermocouple E (chromel / constantan)

Thermocouple of this type can be represented by a ninth-degree polynomial as in Table 1. Voltage generated as a function of temperature from 0 $^{\circ}$C to 900 $^{\circ}$C can be calculated, as can temperature as a function of voltage using the inverse relationship. For the latter case, temperature is given to 0.1 $^{\circ}$C from 0 $^{\circ}$C to 900 $^{\circ}$C

Thermocouple K (chromel / alumel)

The outputs of there thermocouples can be represented in Table 1. A temperature equation with an exponential term is used to generate values of voltage as a function of temperature from 0 $^{\circ}$C to 1250 $^{\circ}$C. The inverse relation provides reference temperature accurate to 0.02 $^{\circ}$C from 400 $^{\circ}$C to 1250 $^{\circ}$C

Thermocouple R and S (platinum –10% rhodium / platinum)

The outputs of their thermocouple can be represented in Table 1. A temperature equation used to generate voltages for this type thermocouple. From 0 $^{\circ}$C to 1450 $^{\circ}$C

Thermocouple B (platinum –30% rhodium / platinum)

Table 1 is used to generate these voltages as a function of temperature from 800 $^{\circ}$C to 1700 $^{\circ}$C

ARDUINO

Arduino is the Italian language with a distinctive accent, and there is no official Thai language. Some people read that Ar-dui-we-no, Ar-dea-no or Ah-ar-dui-no and other. Arduino is featured in the easy to learn and use, due to the design of the command to support the using, and the simple form is not complicated. Although the Arduino has a pattern, similar to the microcontroller such as Basic Stamp of Parallax, BX-24 of Net medias and Handy Board of MIT. There are featured a lot of other, such as: (Marco Schwartz, 2016)

1. Low cost, the source code and the circuit can be connected to the circuit itself.
2. The program is developed Arduino support both Windows, Linux and Macintosh OSX.
3. There is a command format easy to use, can be used to really be very complex
4. Developed further to meet the needs of both Hardware and Software.

ESP8266 module

The ESP8266 chip is Teo Swee Ann, ESP chip creator, Espressif System company. The module includes Microcontroller + WiFi Module. It can be used instead of microcontrollers. The program space is up to 4MB, leaving space for programming.

Features of the board ESP8226

ESP8226 were operated at 3.3 – 3.6 V. The compatible with other sensors using 5V. The voltage divider must be used to prevent damage to the module. The maximum active module current is 200 mA, frequency is 40 MHz. The deployed devices that operate at a frequency such as LCD. The data display is faster than microcontrollers.

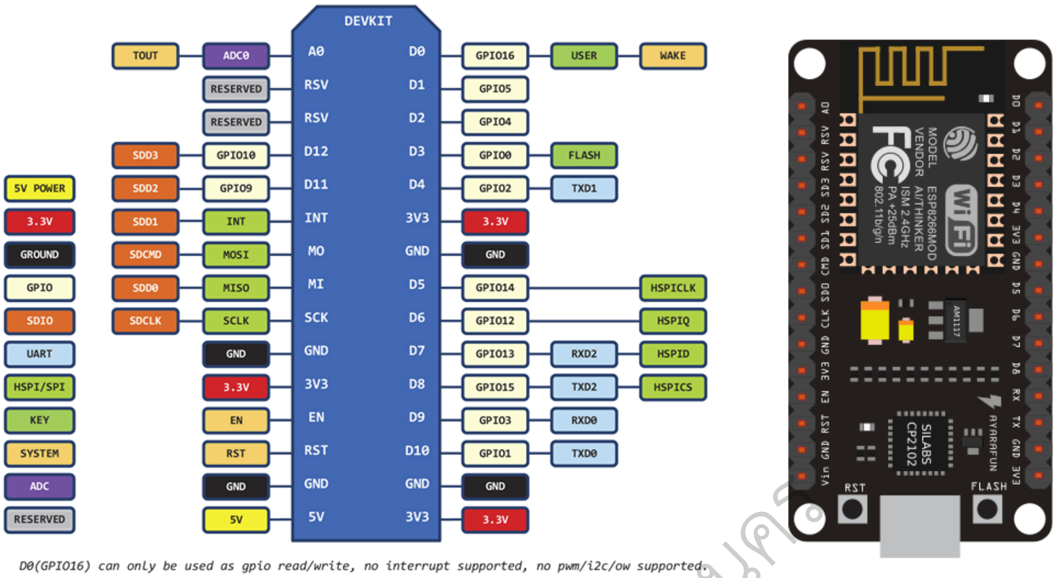

Figure 9 Show the system diagram of the ESP8266. (http://aj-bee.blogspot.com/2015/09/nodemcu-v2-esp8266-part-1.html)

This development kit based on the WiFi module ESP8226

1. GPIO PWM, I2C, 1-wire and ADC are included on one board.

2. The USB-TTL is not as split the regular ESP8226, the easy to used.

3. GPIO can be PWM, I2C and 1-wire.

4. PCB antenna for the wireless transmitter.

5. Use a micro-USB connector for +5V and firmware download

LITERATURE REVIEWS

Yuan Yu et al. reported enhancing the thermoelectric performance of free solidified p–type $Bi_{0.5}Sb_{1.5}Te_3$ alloy by manipulating its parent liquid state. It found that the maximum ZT = 0.78 at 442 K (Yuan Yu, Bin Zhu & Fang-qiu Zu, 2015) as shown in Figure 10.

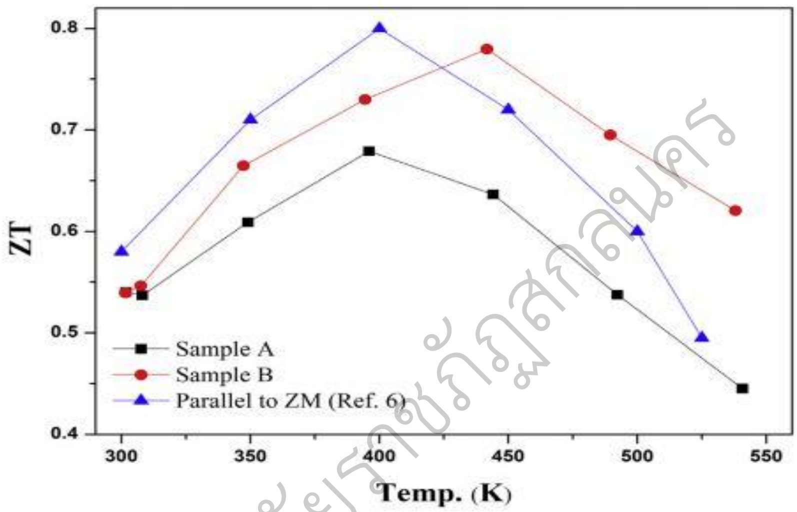

Figure 10 The relationship between temperature and the ZT of $Bi_{0.5}Sb_{1.3}Te_3$.

GoEun et al. reported synthesis of Bi_2Te_3 and Bi_2Se_3 by melted method at 1024 K for 4 h and ground to a size of 75 microns. Before the hot pressing at 673 K under 70 MPa for 1 h in argon atmosphere. The maximum ZT = 0.56 of $Bi_2Te_{2.85}Se_{0.15}$ and 0.60 at 423 K of $Bi_2Te_{2.4}Se_{0.6}$ (Go–Eun and Il–Ho Kin, 2014) as shown that in Figure 11

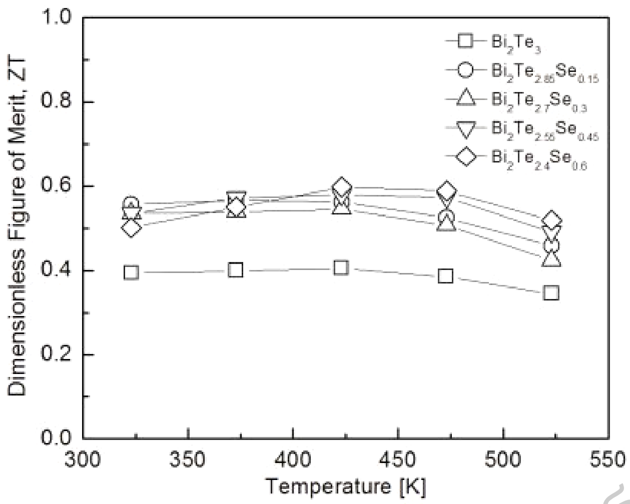

Figure 11 The relationship between temperature and the ZT of $Bi_2Te_{3-y}Se_y$.

L.P. Hu et al. reported thermoelectric properties of Bismuth telluride, n-type by method at 1073 K for 10 h. Before the hot pressing at temperature 673 K for 30 minutes under 80 MPa. The maximum ZT = 1.0 at 513 K (L.P. Hu, X.H. Liu & X.B. Zhao, 2012), as shown that in Figure 12

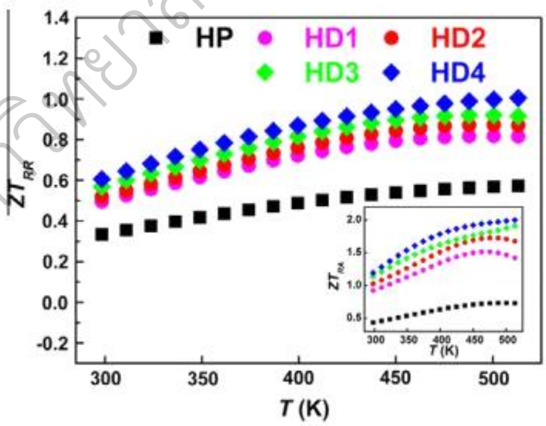

Figure 12 The relationship between temperature and the ZT of $Bi_2Te_2Se_1$.

Chan-Chieh et al. reported the thermoelectric properties of Bismuth Telluride by doping Pb and PbTe, melt method at 923 K for 24 h Before the hot pressing at 732 for 1 h under 60 MPa. The maximum ZT = 1.0 at 350 K of doped Pb and 0.7 at 475

K of doped PbTe, (Chan-Chieh Lin, Dianta Ginting & Jong-Soo Rhyee, 2016) as shown in Figure 13

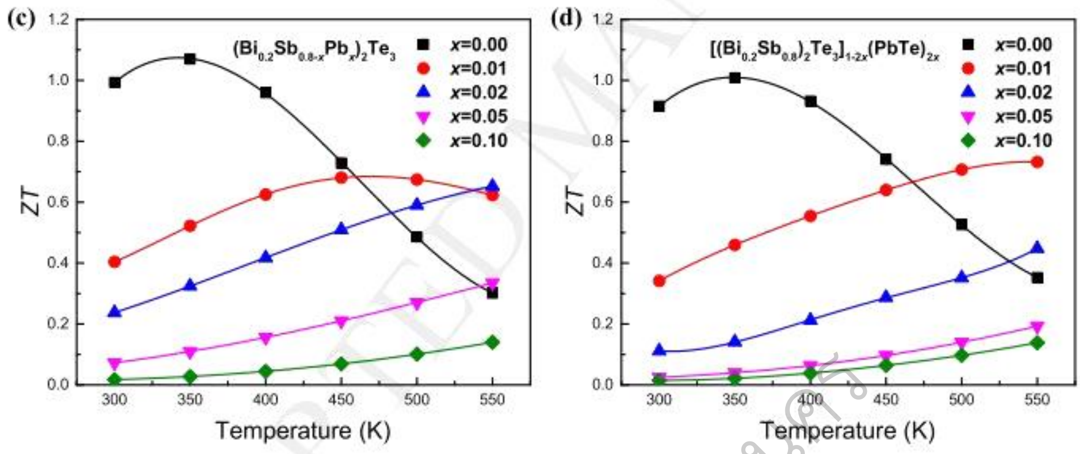

Figure 13 The relationship between temperature and the ZT of $(Bi_{0.2}Sb_{0.8-x}Pb_x)_2Te_3$ and $\{(Bi_{0.2}Sb_{0.8})_2Te_3\}_{1-2x}(PbTe)_{2x}$

Qinghui Jiang et al. reported carrier concentration tailoring and phonon scattering from n-type zinc oxide (ZnO) non-inclusion in p-type and n-type bismuth tellurid (Bi_2Te_3): Leading to ultra-low thermal conductivity and excellent thermoelectric properties. The Bi_2Te_3 polycrystalline materials can be supposed to ne isotropic when the sample are prepared by SPS at 450 °C under 50 MPa, the maximum of ZT = 1.3 at 60 °C as shown in Figure 14 (Qinghui Jiang, Junyou Yang & Haixue Yan, 2017).

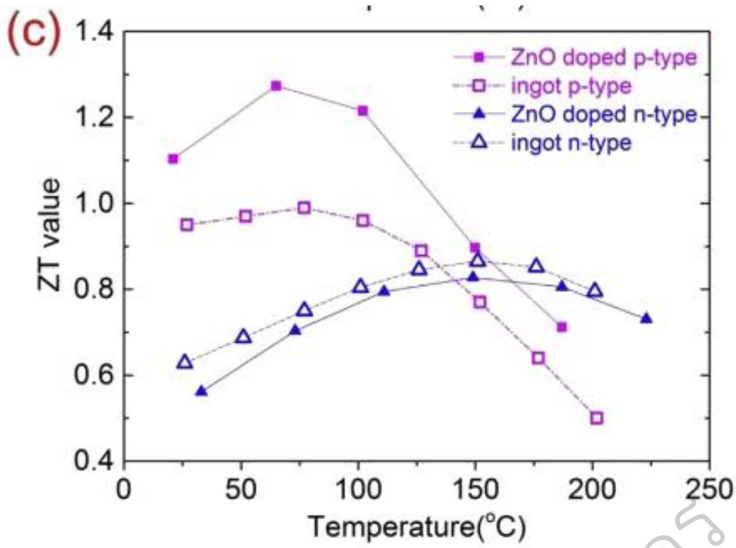

Figure 14 The relationship between temperature and the ZT of Bi_2Te_3

Anil K. Bohra et al. reported tellurium- free thermoelectric: Improved thermoelectric performance of n-type Bi_2Se_3 having multiscale hierarchical architecture. For preparation pf sample by vacuum melting route, stoichiometric amount of Bi and Se (99.99%) in a clean quartz under a base pressure of 2×10^{-5} mbar. The vacuum sealed ampoule was kept in a home-made rocking furnace for uniform mixing of initial charges at 1073 K for 4 h with heating rate of 50 °C h^{-1}. The ingot thus obtained was reground to fine powder and vacuum hot-pressed at 873 K, the maximum of ZT = 0.96 at 370 K as shown in Figure 15 (Anil K Bohra, Rana Bhatt & S.C. Gadkari, 2017).

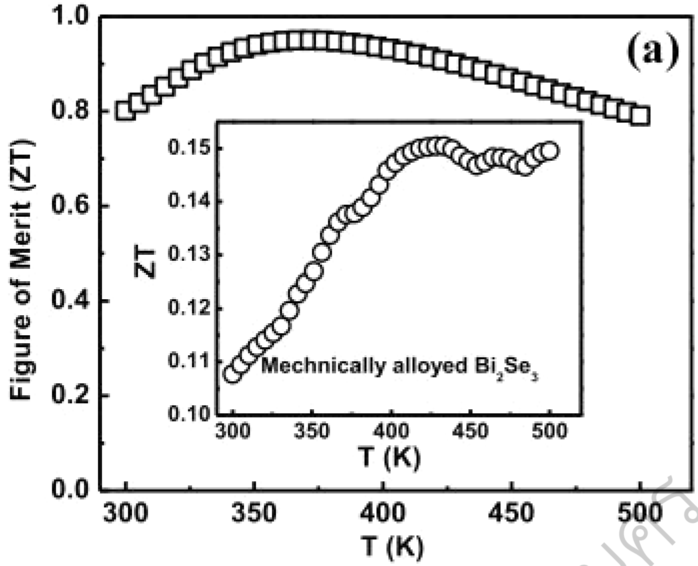

Figure 15 The relationship between temperature and the ZT of mechanically alloyed Bi_2Se_3

Hyunyong Cho et al. eeported Enhancement of thermoelectric properties in CuI-doped $Bi_2Te_{2.7}Se_{0.3}$ by hot-deformation, fabricated by a repetitive hot-deformation process. The ampoule was sealed under a high vacuum (10^{-5} Torr). The ampoule was heated to 1073 K for 24 h, and then was cooled slowly for 30 h in the furnace. The maximum ZT = 1.07 was achieved at 423 K as shown in Figure 16 (Hyunyong Cho, Jin Hee Kin & Su-Dong Park, 2018).

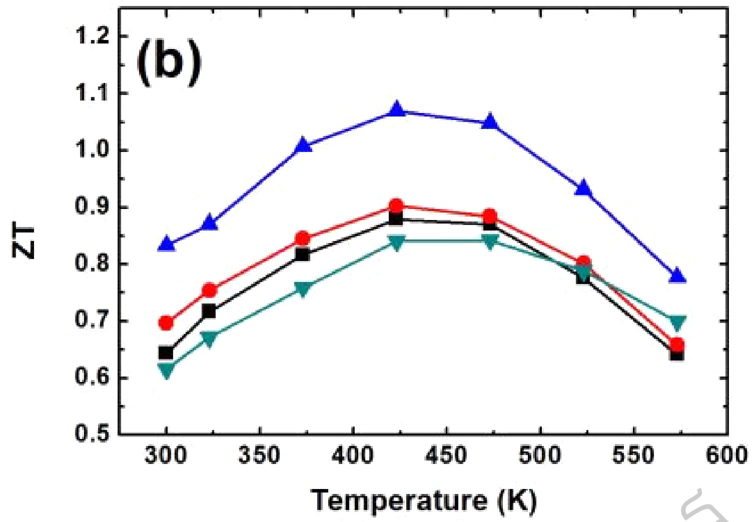

Figure 16 The relationship between temperature and the ZT of $Bi_2Te_{2.7}Se_{0.3}$.

Zhenxiang Yi et al., reported the effect of thermoelectric sensor was using GaAs are conductor. The thermal conductivity on surface of GaAs and Seebeck coefficient were changed with temperature. It will affect the output of the sensor in experimental, and measure the voltage at a temperature of 273 – 363 K (Zhenxiang Yi, Xiaoping & Hao Wu, 2014), as shown that in Fig. 17

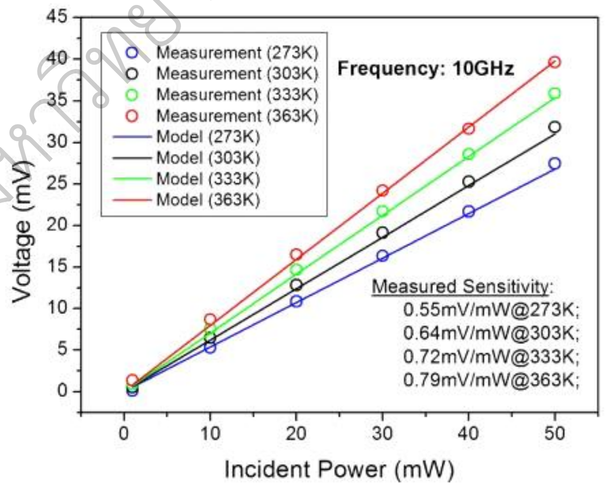

Figure 17 Shown the voltage that occurs at various temperatures at 10GHz.

J.J. Kuchle et al. reported thermoelectric wireless, for information about wireless operating system in real time to external location (J.J. Kuchie and N.D. Love, 2014)

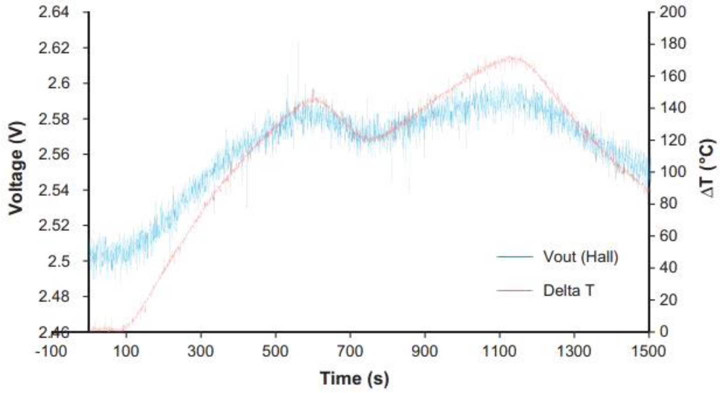

Figure 18 Show the relationship between voltage and time

Yongming Shi et al. reported a novel self-powered wireless temperature sensor based on thermoelectric generators. For the using the thermoelectric generators allows, the sensor to operate without a generator or other (Yongming Shi, Yao Wang Deng & Huihong Ye, 2014)

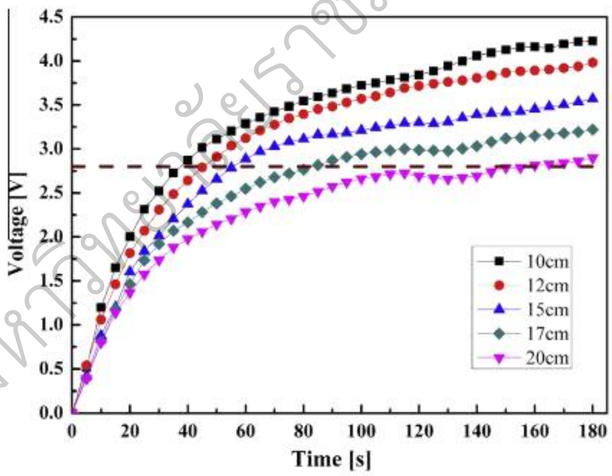

Figure 19 Show the relationship between voltage and time

Shaowei Qing et al. reported characteristics and parametric analysis of a novel flexible ink-based thermoelectric generator for human body sensor. The structure of flexible ink-based TEG with several rows. This study proposes design of a flexible thermoelectric generator, which is part of a sensor and supplies required electric power for human body application. The maximum output power can reach 0.2 μW cm^{-2}.

Huan Cheng et al. reported Flexible cellulose-based thermoelectric sponge towards wearable pressure sensor and energy harvesting. In this work, a flexible cellulose-based TE sponge (CP: PP sponge) was prepared via the electrostatic assemble of poly (3,4- ethlenedioxythhiophene): poly (styrene sulfonate) (PEDOT: PSS) on cellulose sponges crosslinked with branched polyethyleneimine (CP sponge). The output voltage increases proportionally with ΔT, reaching a maximum of 0.5 mV at 30 K (Huan Cheng, Yirui Du & Xiaofeng Sui, 2018).

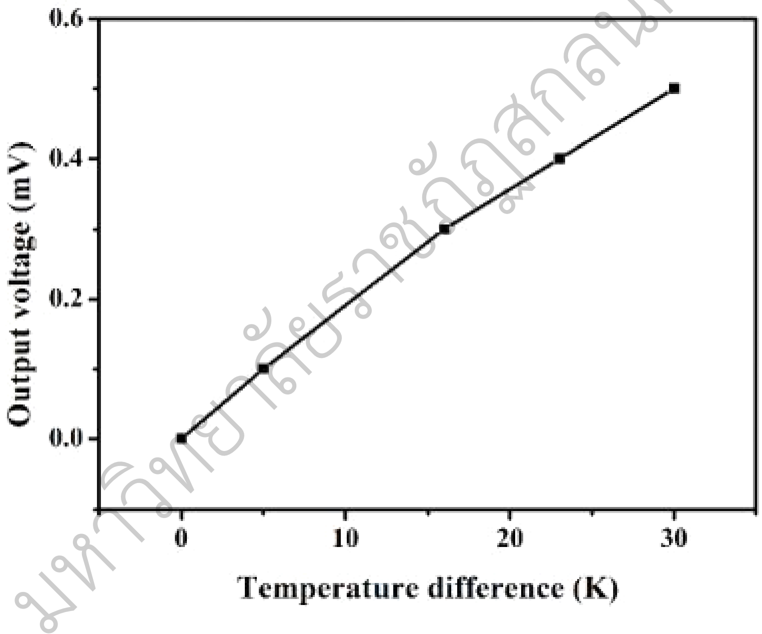

Figure 20 The output voltage of the device at different temperature difference.

Table 2. Brief summary of ZT for various thermoelectric materials.

Year	Materials	Author	Method	ZT
2012	$Bi_{85}Sb_{15-x}Pb_x$	Z.chen et al.	Pressure less sintering	0.11 at < 25 °C
2012	Bi_2Te_3	L.P. Hu et al.	Hot pressing	1.0 at 513 K
2015	$Bi_{0.5}Sb_{1.5}Te_3$	Yuan Yu et al.	Liquid state	0.78 at 442 K
2014	$Bi_2Te_{2.85}Se_{0.15}$	Go-Eun Lee et al.	Hot pressing	0.56 at 323 K
2016	Bi_2Te_3 doping Pb and PbTe	Chan-Chieh et al.	Hot pressing	1.0 at 350 K, 0.7 at 475 K
2017	Bi_2Te_3	Qinghui Jiang et al.	spark plasma sintering	1.3 at 330 K
2017	Bi_2Se_3	Anil K. Bohra et al.	Hot pressing	0.96 at 370 K
2018	$Bi_2Te_{2.7}Se_{0.3}$	Hyunyong Cho et al.	Hot-deformation	1.07 at 423 K