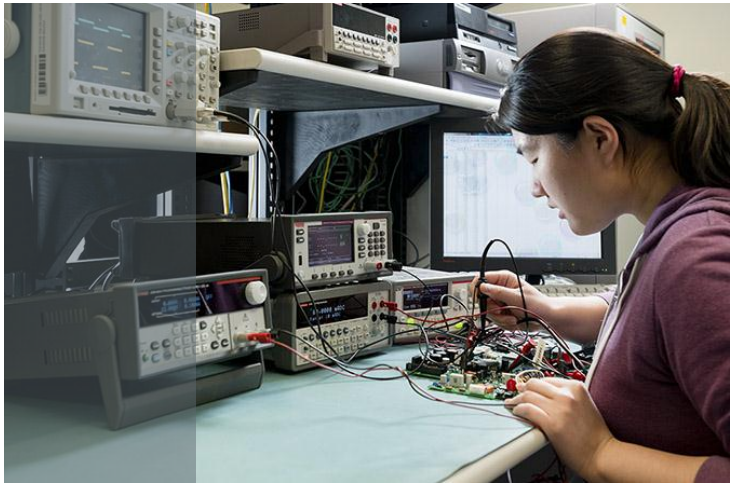
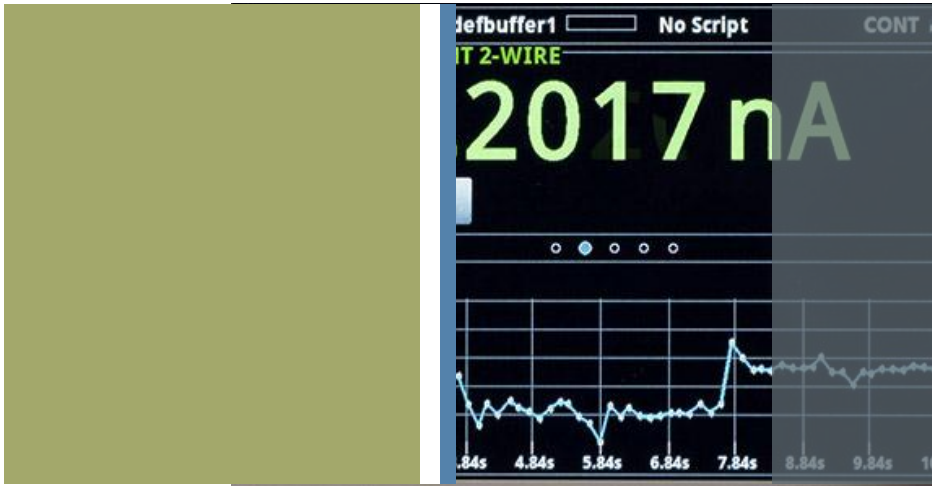
에너지 하베스팅의 핵심이 되는 열전소자 측정 기술

텍트로닉스
김수길부장





KEITHLEY
A Tektronix Company

Tektronix®

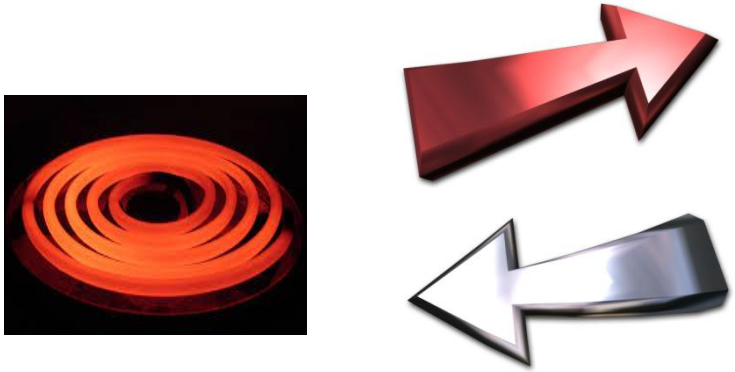
Contents

- Background of Thermoelectric Device
- Seebeck Effect/Peltier Effect
- TE Device Applications
- TE Device Measurement Instruments

Thermoelectric Device

- Thermoelectric effect is direct conversion of temperature difference to electric voltage and vice versa
- Thermoelectric device creates voltage with temperature difference between the two plates.

Electrical Energy



Heat Energy

Conversion

Thermoelectric Effect

= Seebeck Effect + Peltier Effect

Key Factor is thermoelectric figure of merit as follows

$$ZT_m = \frac{S^2 \sigma T_m}{k}$$

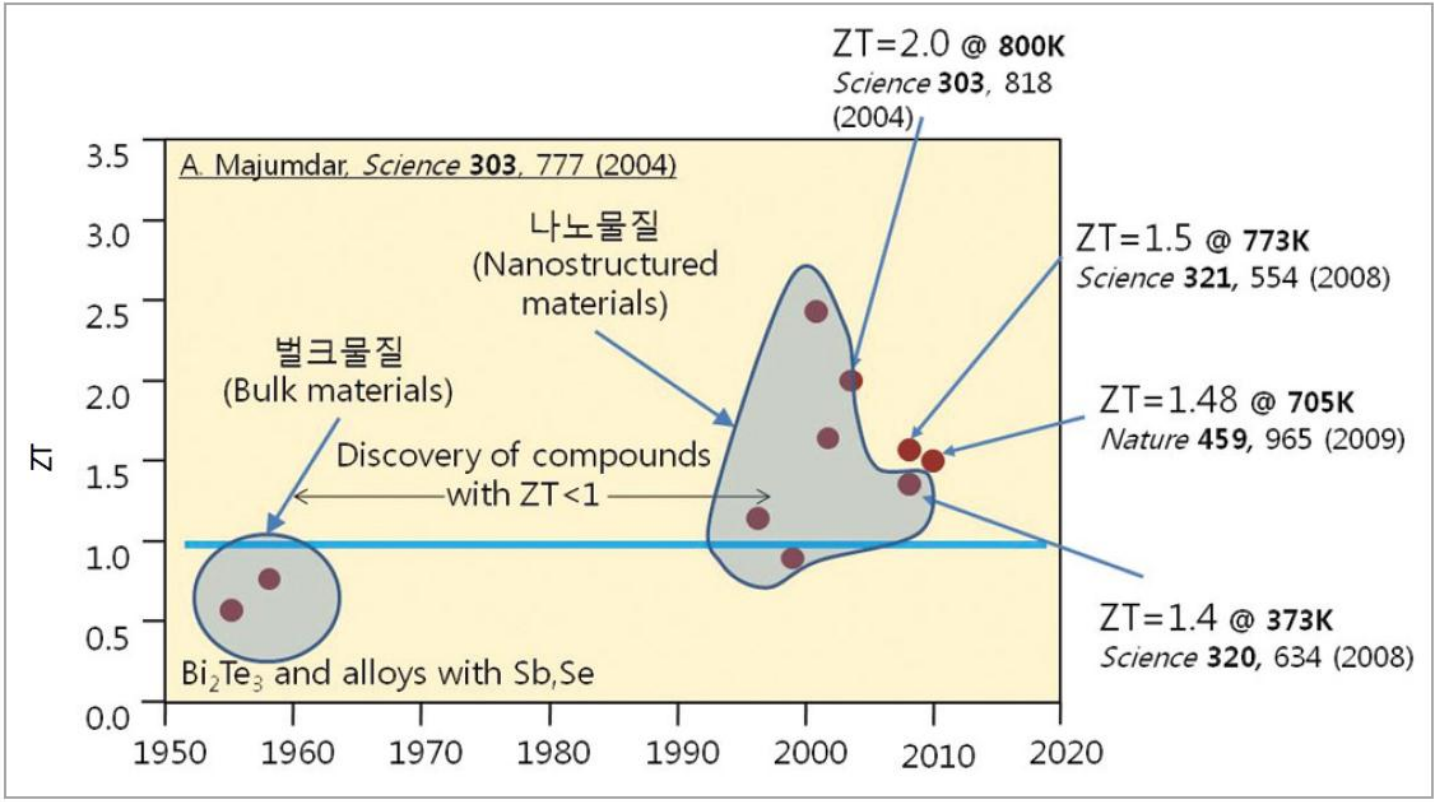
ZT_m	Thermoelectric figure of merit
S^2	Seebeck Coefficient
σ	Electrical Conductivity
k	Thermal Conductivity
$S^2\sigma$	Power Factor

Research Points

1. How to increase figure of merit from 1
2. How to increase electrical conductivity or power factor
3. How to reduce thermal conductivity

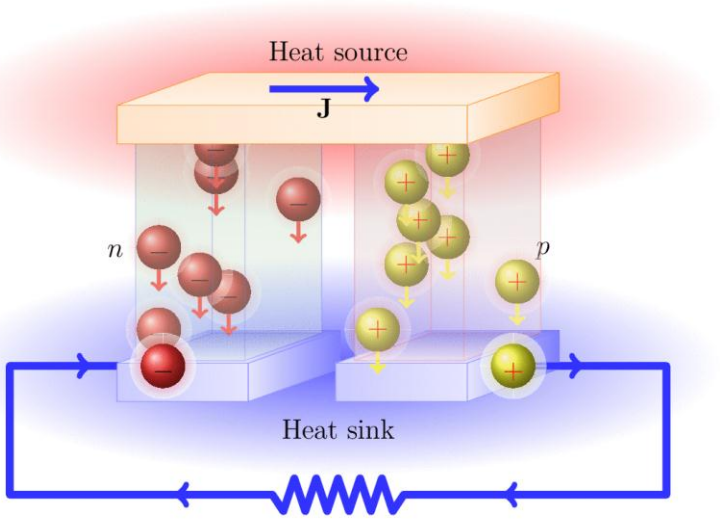
* Problem is that power factor is in proportion to thermal conductivity

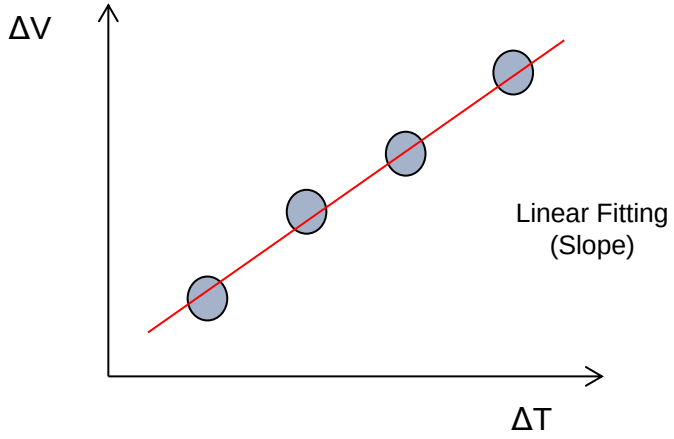
Figure of Merit Trend



Bulk material has below figure of merit1
Nanostructed material and compounds has higher than figure of merit 1
By reducing thermal conductivity
Higher than 1.5 is affordable to use it. Over 3 can be expected.

Seebeck Effect





$$E_{emf} = -S\Delta T$$

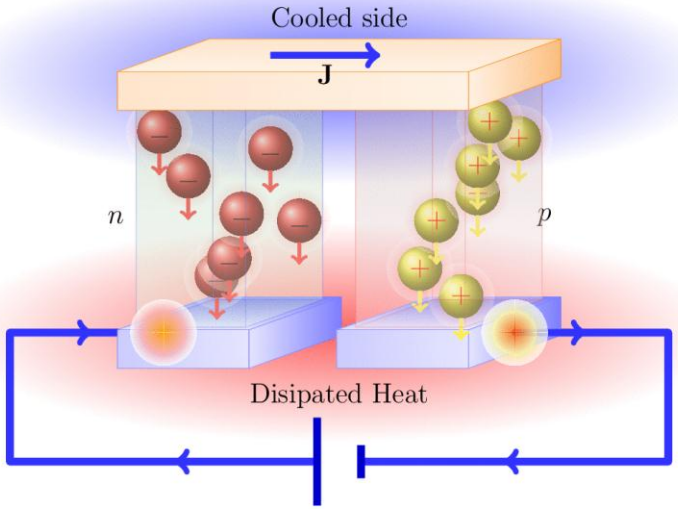
$$S = \frac{\Delta V}{\Delta T}$$

Temperature gap create electromotive force
After settling, voltage can be monitored
Measurement temperature by reading voltage(thermocouple)
Electrical energy generation by temperature (Energy harvest)

KEITHLEY
A Tektronix Company

Tektronix®

Peltier Effect



$$Q = (\Pi_A - \Pi_B)I$$

Π_A, Π_B Peltier Coefficient of conductor A,B

I Current from A to B

$Q = (\Pi_A - \Pi_B)I$
Π_A, Π_B
I

Peltier coefficient represent how much heat is carried per unit charge.
Charge current flow over junction with heat flow.
If there is difference in two coefficients, current flow will develop a discontinuity of heat flow
Cooled side looses heat, hot side gain heat

KEITHLEY
A Tektronix Company
Tektronix®

TE Device Applications

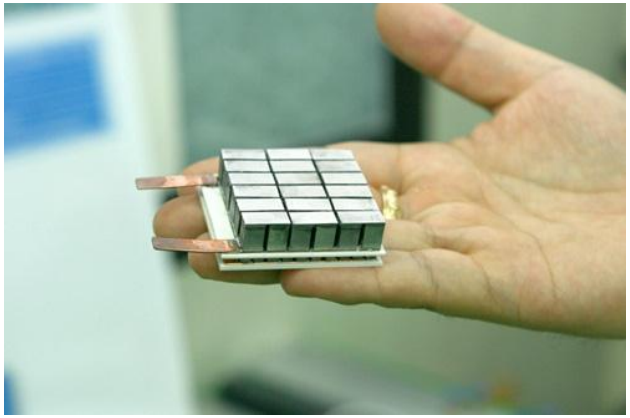
BMW 5 Series

By TE device, heat from engine is converted to electrical energy.
Re-use it to heat seat

TDDI in Japan

Thermoelectric refrigerator is selling

TE Device Applications more



- Fits 12 Wine bottles
- Double tempered glass door
- Reduced noise operation (15dB)
- Reversible door
- Internal light
- Adjustable temperature control
- Environmentally friendly
- Wind cooling system
- Thermo electric refrigeration
- Low power consumption

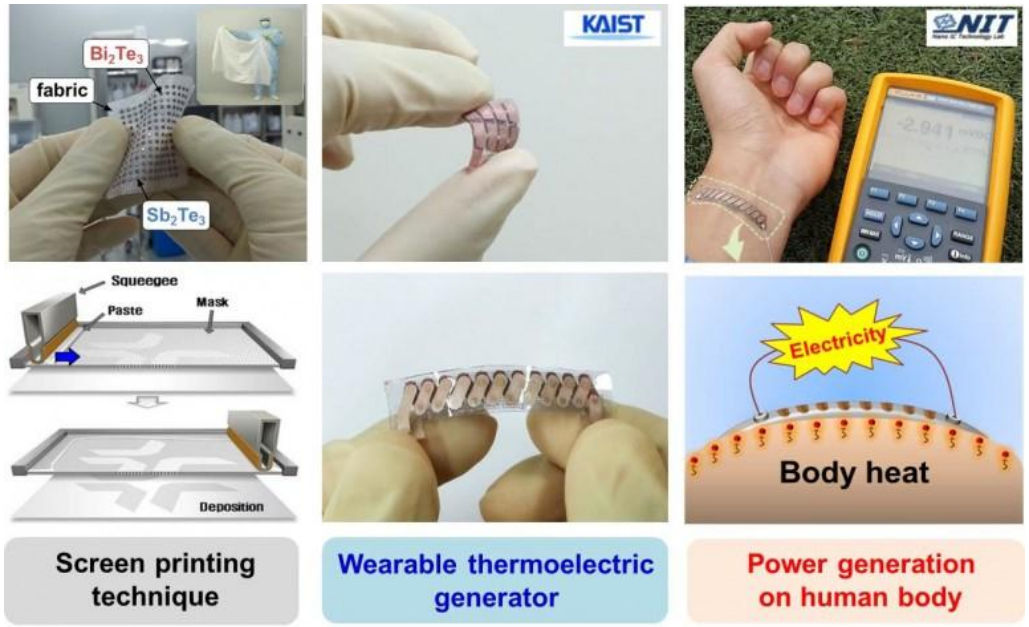
KERI

Compound thermoelectric module to covert heat into electric energy directly

ACE TEC

Wine cooler using thermoelectric device

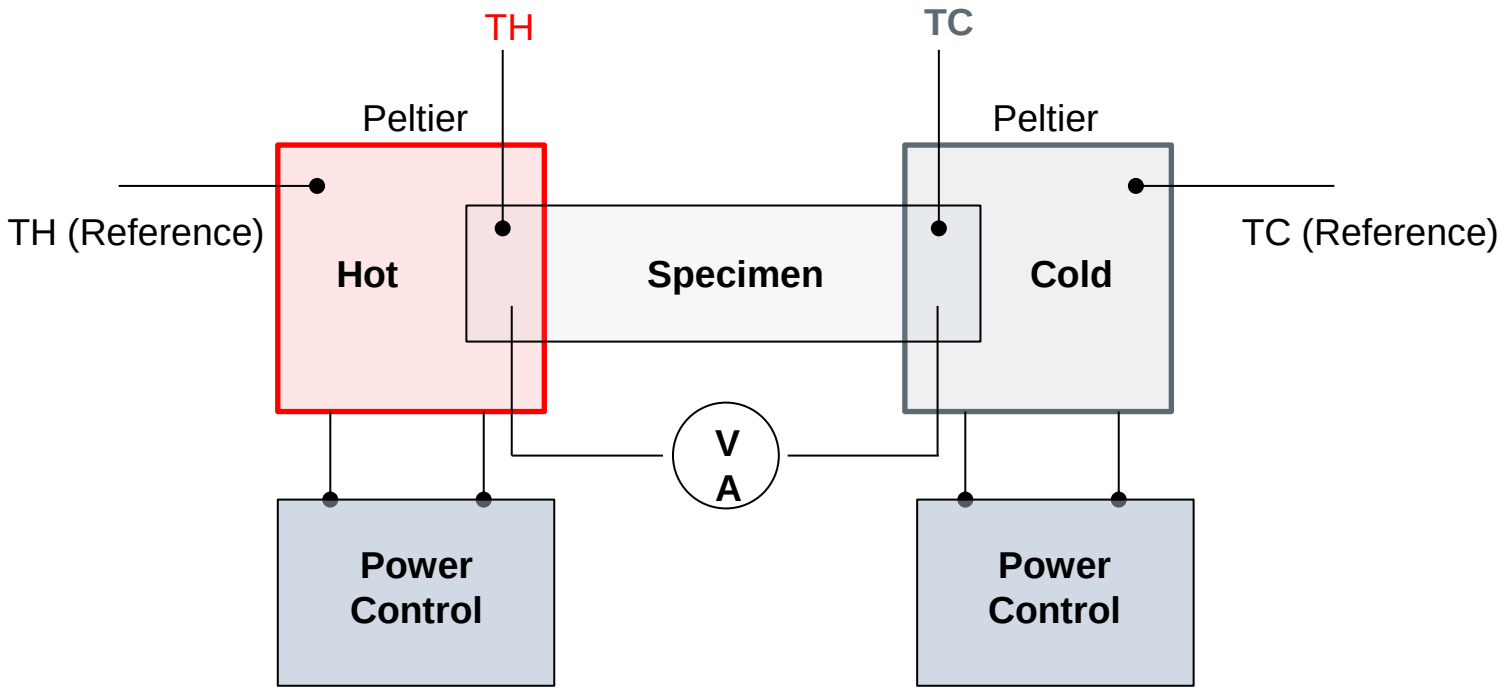
TE Device Applications more



KAIST

Wearable generator
Power generation from human body

TE Device Test Setup



Step 1. Apply current to peltier device with one or two current sources to heat or cool the plate
Step 2. Measure voltage or current in the TE device
Step 3. As temperature goes on, measure voltage, plot Seebeck.
* Measurement of electrical conductivity on device

TE Device Measurement Parameters

Measurement

- Voc : Open Circuit Voltage Measurement as maximum voltage from the device
- Isc : Short Circuit Current Measurement as maximum current from the device
- Temperature Measurement, plot Seebeck graph
- Electrical conductivity measurement by Van Der Pauw.

Source

- Very accurate current source to control temperature

TE Device Measurement Instruments

2182A Nano Voltmeter

Low level voltage measurement for Voc
Electrical Conductivity Measurement

DC Noise Performance [7] (DC noise expressed in volts peak-to-peak)

Response time = time required for reading to be settled within noise levels from a stepped input, 60Hz operation.

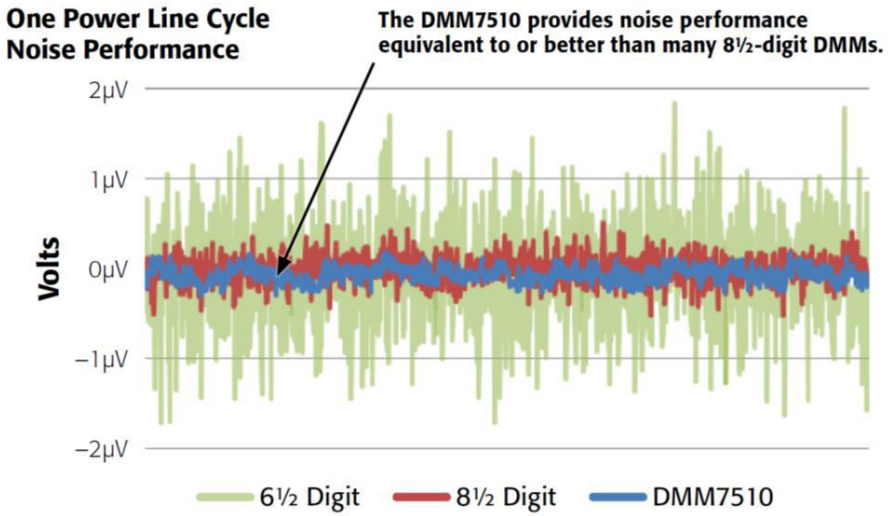
Channel 1

Response Time	NPLC, Filter	Range 10 mV	100 mV	1 V	10 V
25.0 s	5, 75	6 nV	20 nV	75 nV	750 nV
4.0 s	5, 10	15 nV	50 nV	150 nV	1.5 μV
1.0 s	1, 18	25 nV	175 nV	600 nV	2.5 μV
667 ms	1, 10 or 5, 2	35 nV	250 nV	650 nV	3.3 μV
60 ms	1, Off	70 nV	300 nV	700 nV	6.6 μV
Channel 2 [6, 10]					
25.0 s	5, 75	—	150 nV	200 nV	750 nV
4.0 s	5, 10	—	150 nV	200 nV	1.5 μV
1.0 s	1, 10 or 5, 2	—	175 nV	400 nV	2.5 μV
85 ms	1, Off	—	425 nV	1 μV	9.5 μV

KEITHLEY
A Tektronix Company

Tektronix®

TE Device Measurement Instruments



New DMM 7410

Measurement for Voc.
Precisely analyze current and voltage waveforms and transients with 1MS/sec, 18-bit digitizer
Large reading memory (27.5 million) to capture more of your signal

KEITHLEY
A Tektronix Company
Tektronix®

TE Device Measurement Instruments

6485 Picoammeter

Low level current measurement for Isc
Low level to 400fA accuracy

Range	5½ Digit Default Resolution	Accuracy (1 Year) [1] ±(% rdg. + offset) 18°–28°C, 0–70% RH	Typical RMS Noise [2]	Analog Rise Time [3] (10% to 90%)
2 nA	10 fA	0.4 % + 400 fA	20 fA	8 ms
20 nA	100 fA	0.4 % + 1 pA	100 fA	8 ms
200 nA	1 pA	0.2 % + 10 pA	1 pA	500 µs
2 µA	10 pA	0.15% + 100 pA	10 pA	500 µs
20 µA	100 pA	0.1 % + 1 nA	100 pA	500 µs
200 µA	1 nA	0.1 % + 10 nA	1 nA	500 µs
2 mA	10 nA	0.1 % + 100 nA	10 nA	500 µs
20 mA	100 nA	0.1 % + 1 µA	100 nA	500 µs

KEITHLEY
A Tektronix Company

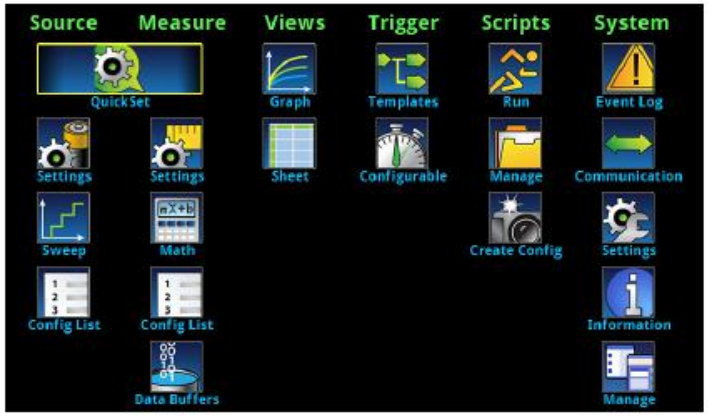
Tektronix®

TE Device Measurement Instruments

2460 Source Meter

Current Source for temperature control
Generate high current up to 7A.
Touch screen instruments

2460 main home screen



The Model 2460's icon-based menu structure helps even novice users configure tests quickly and confidently.

KEITHLEY
A Tektronix Company

Tektronix®

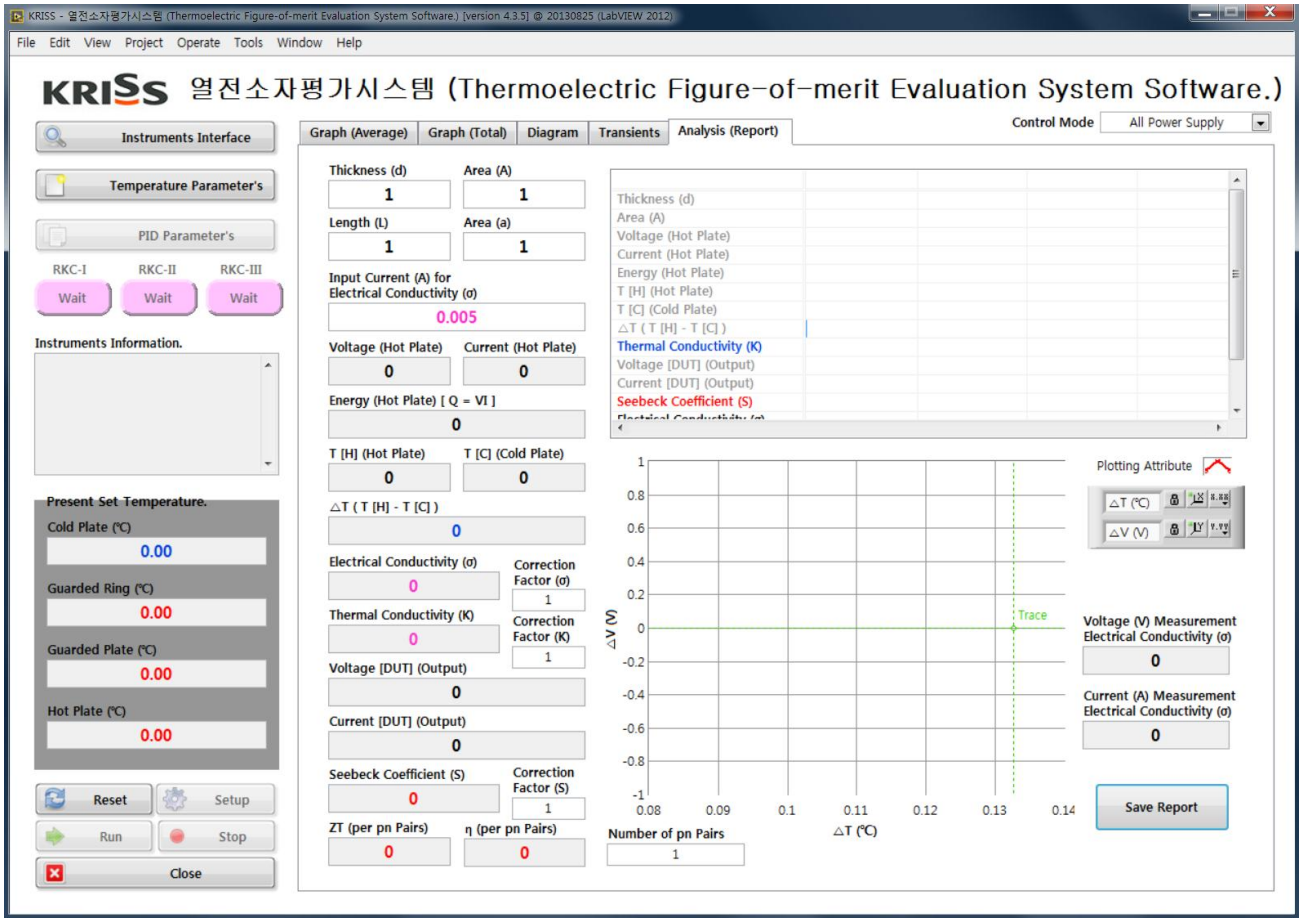
TE Device Measurement Software Example

Typical TE Device Measurement Software provided by channel SnM
Temperature, Power, Seebeck plot

KEITHLEY
A Tektronix Company

Tektronix®

TE Device Measurement Software Example

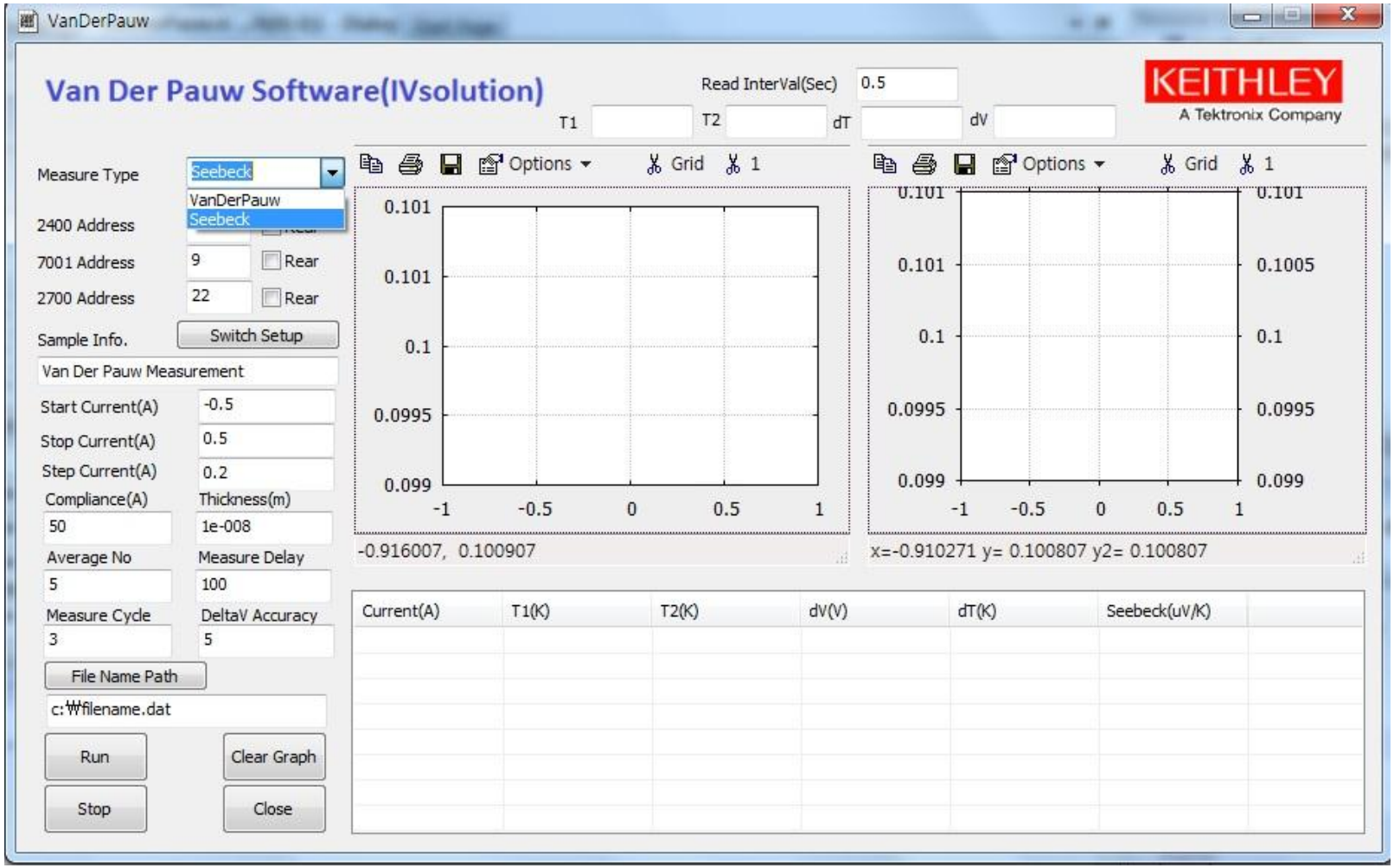


TE Figure of Merit Evaluation Software provided by channel SnM
Electrical conductivity, Seebeck, Figure of merit plot

KEITHLEY
A Tektronix Company

Tektronix®

TE Device Measurement Software Example



KEITHLEY
A Tektronix Company

Tektronix®

Conclusion

- Thermoelectric Device is technology to convert heat into electrical energy and vice versa

- Keithley provide perfect test solution for TE device in instruments Nano voltmeter, DMM, Picoammeter, and SourceMeter.

- Keithley also provide total software to measure Seebeck, and Figure of merit.


Tektronix
KEITHLEY
A Tektronix Company