Thermoelectric Properties of N type Mg_3Bi_2-N type Bi_2Te_3 Composites

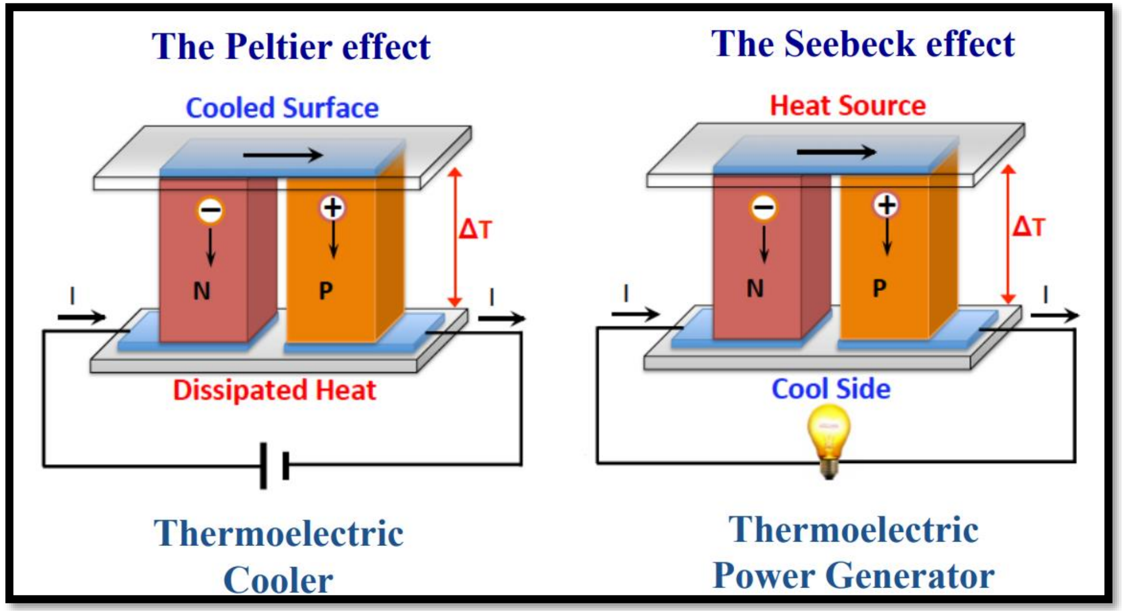
Junaid Ur Rehman

Outlines

- Introduction
- Applications
- Characterization and Results
- Conclusion

Introduction

1. Basic Principles



2. Figure of Merit

Material: $zT = \frac{S^2 \sigma}{k} T$

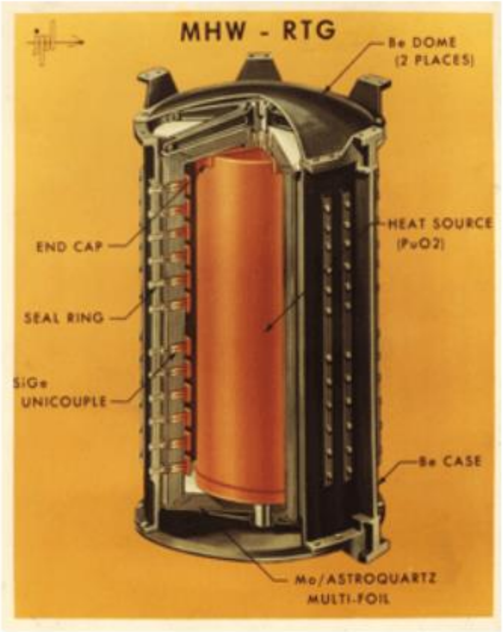
Seebeck coefficient (S)
Electrical conductivity (σ)
Thermal conductivity (k)

3. Motivation

- Power stations
- 65% of energy wasted to environment
- Green house effect

Applications

1. Radioisotope Thermoelectric Generator(RTG)



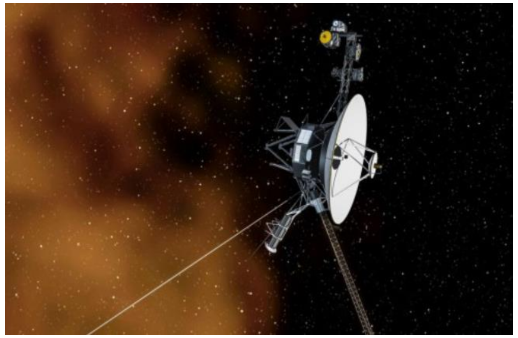
Used by NASA

Apollo-I

Pioneer

Viking

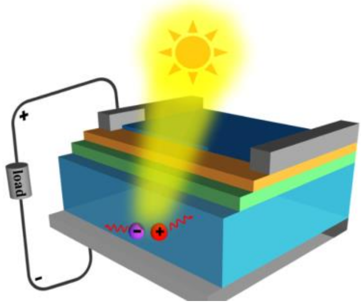
Voyager-I



2. Niche applications for solid state Technology

Peltier coolers based on Bi_2Te_3-Sb_2Te_3 used for

- Optoelectronic devices
- Small refrigerators
- Seat heat and cooling system



Why I choose Composite?

Investigation of near-room and high-temperature thermoelectric properties of $(Bi_{0.98}In_{0.02})_2Se_{2.7}Te_{0.3}/Bi_2Te_3$ composite system

Ganesh Shridhar Hegde[1], A. N. Prabhu[1,*], Ashok Rao[1,2], K. Gurukrishna[1,2], and U. Deepika Shanubhogue[1,2]

JACS JOURNAL OF THE AMERICAN CHEMICAL SOCIETY

Article

Realization of both n- and p-type GeTe Thermoelectrics: Electronic Structure Modulation by AgBiSe2 Alloying

Manisha Samanta, Tanmoy Ghosh, Raagya Arora, Umesh V. Waghmare, and Kanishka Biswas

J. Am. Chem. Soc., **Just Accepted Manuscript** • DOI: 10.1021/jacs.9b11405 • Publication Date (Web): 17 Nov 2019

High thermoelectric potential of Bi_2Te_3 alloyed GeTe-rich phases

Cite as: J. Appl. Phys. **120**, 035102 (2016); https://doi.org/10.1063/1.4958973
Submitted: 29 May 2016 . Accepted: 05 July 2016 . Published Online: 18 July 2016

Naor Madar, Tom Givon, Dmitry Mogilyansky, and Yaniv Gelbstein

N type-N type makes N-type Composites

N type **N type**

$Mg_{3.2}Bi_{1.498}Sb_{0.5}Te_{0.002}$ **$Bi_2Te_{2.7}Se_{0.3}$**

$$(1-x)(Mg_{3.2}Bi_{1.498}Sb_{0.5}Te_{0.002}) + x(Bi_2Te_{2.7}Se_{0.3})$$

Composite

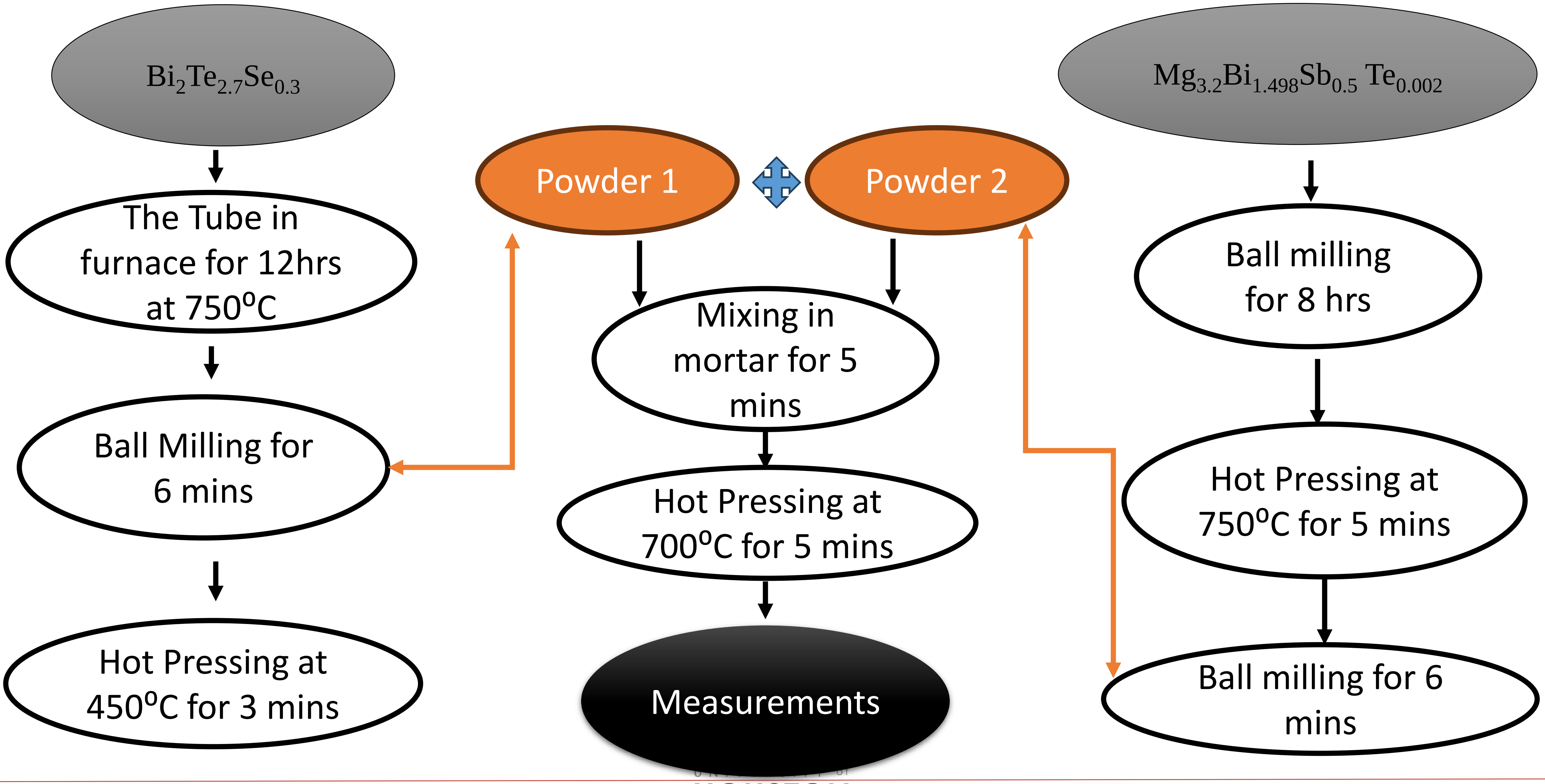
- N type Composite

- Mixing after Hot Pressing
- Direct Mixing Method

Step 1

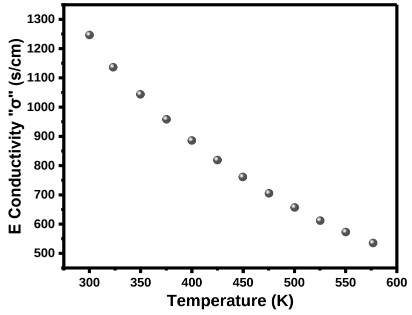
Mixing after Hot Pressing

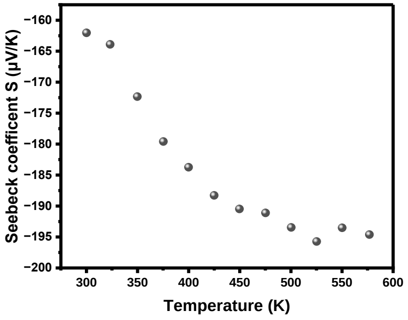
Step 2

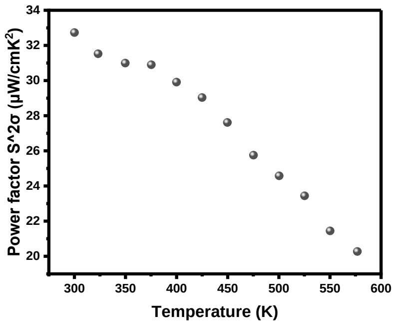


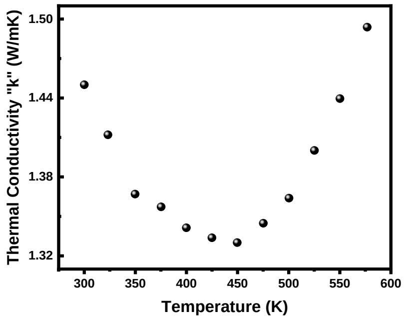
Results

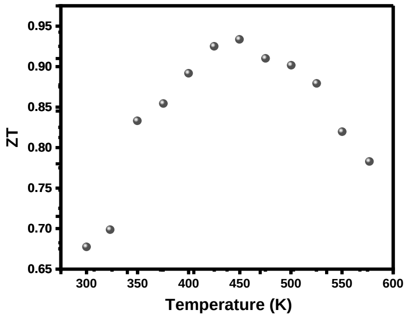
$Mg_{3.2}Bi_{1.498}Sb_{0.5}Te_{0.002}$











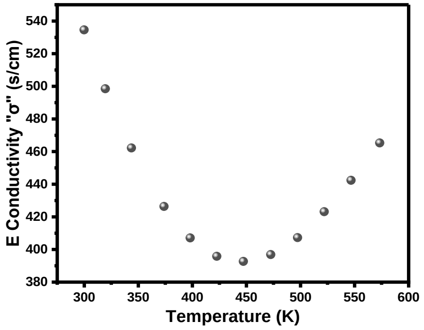
RESEARCH

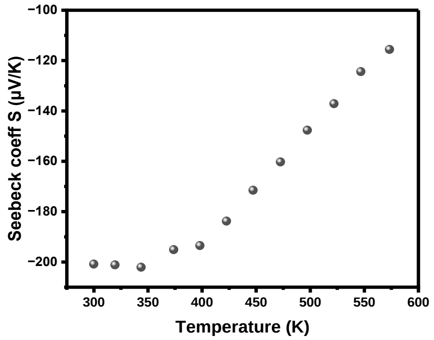
THERMOELECTRICS

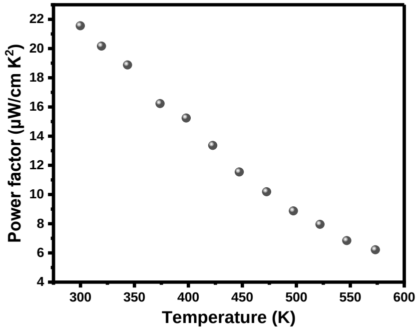
High thermoelectric cooling performance of n-type Mg_3Bi_2-based materials

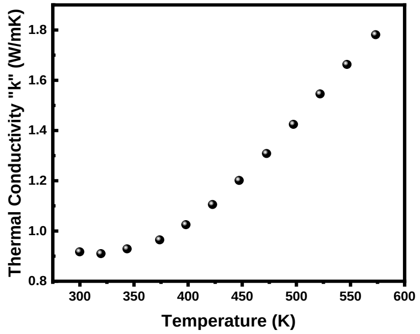
Jun Mao[1], Hangtian Zhu[1], Zhiwei Ding[2], Zihang Liu[1], Geethal Amila Gamage[1], Gang Chen[2*], Zhifeng Ren[1*]

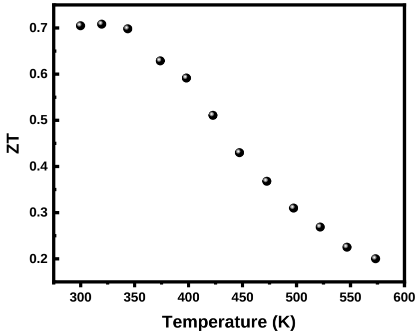
$Bi_2Te_{2.7}Se_{0.3}$

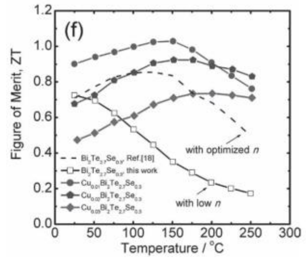








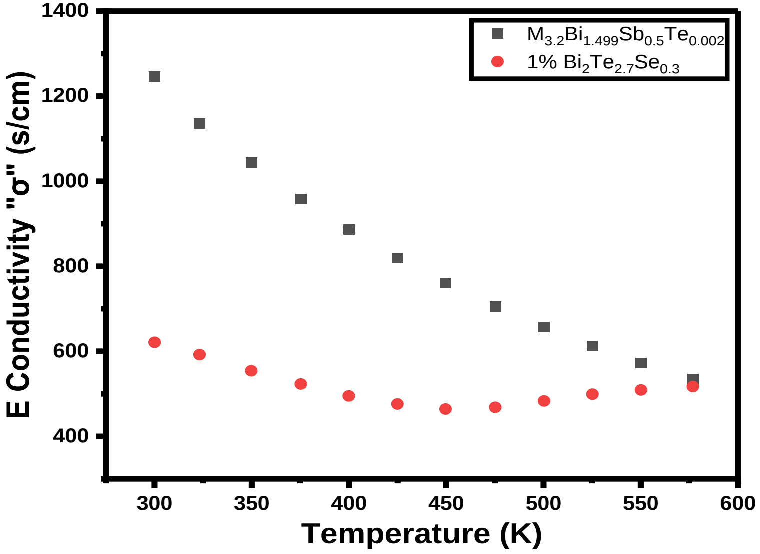


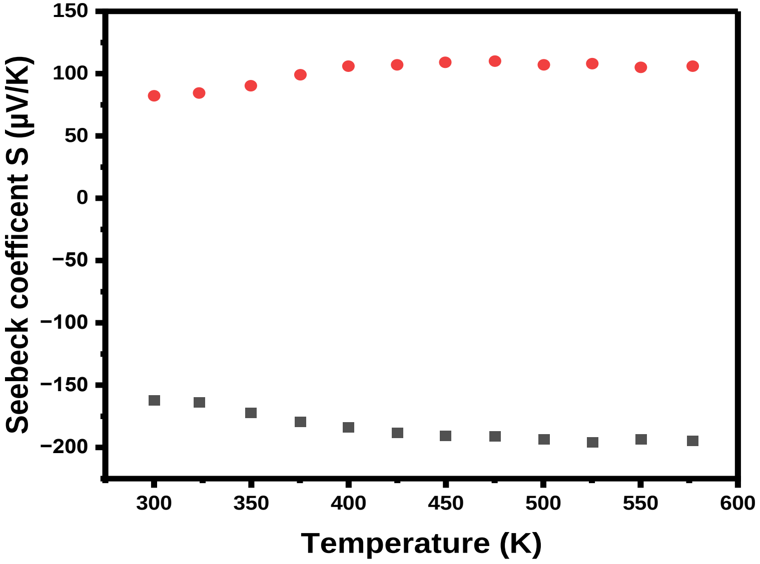


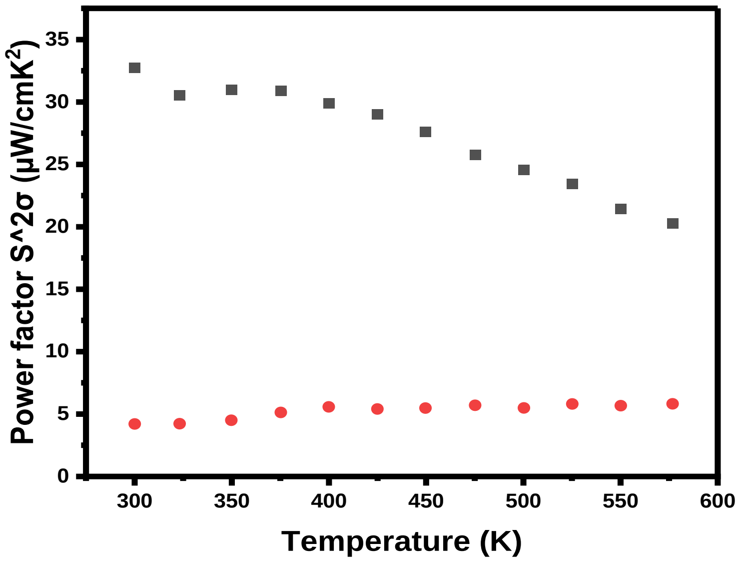
Thermoelectric Property Studies on Cu-Doped n-type $Cu_xBi_2Te_{2.7}Se_{0.3}$ Nanocomposites

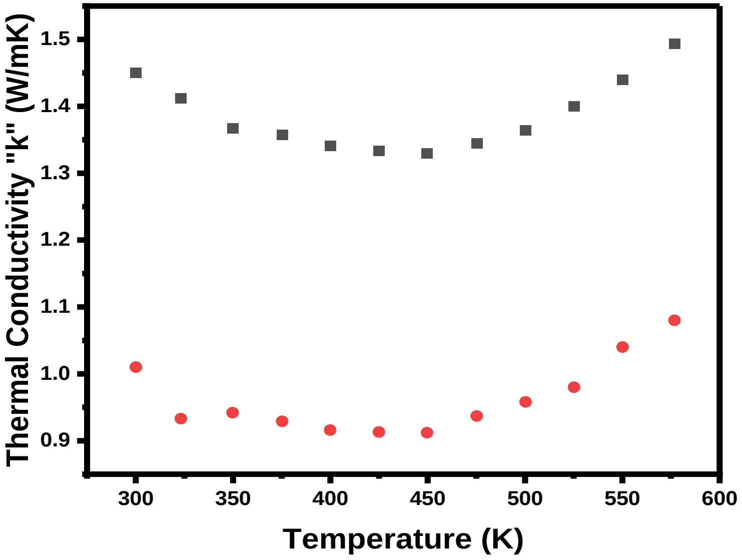
Wei-Shu Liu, Qinyong Zhang, Yucheng Lan, Shuo Chen, Xiao Yan, Qian Zhang, Hui Wang, Dezhi Wang, Gang Chen, and Zhifeng Ren**

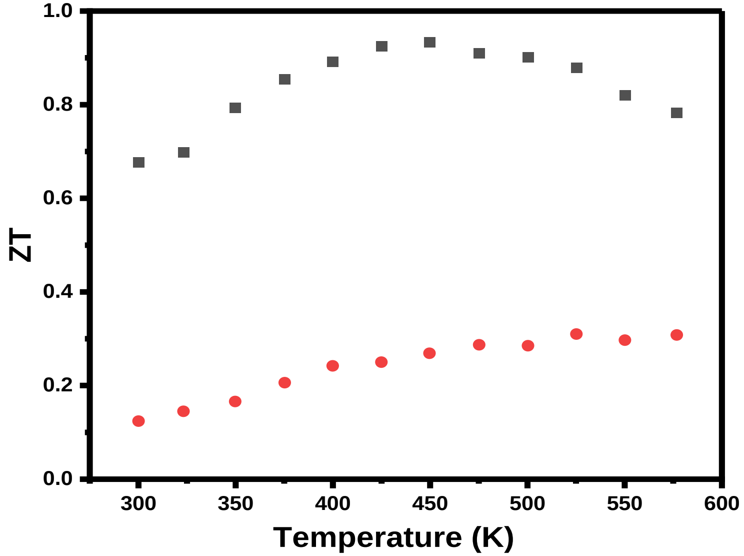
$(1\text{-}x)(Mg_{3.2}Bi_{1.498}Sb_{0.5}\ Te_{0.002}+x(Bi_2Te_{2.7}Se_{0.3})$









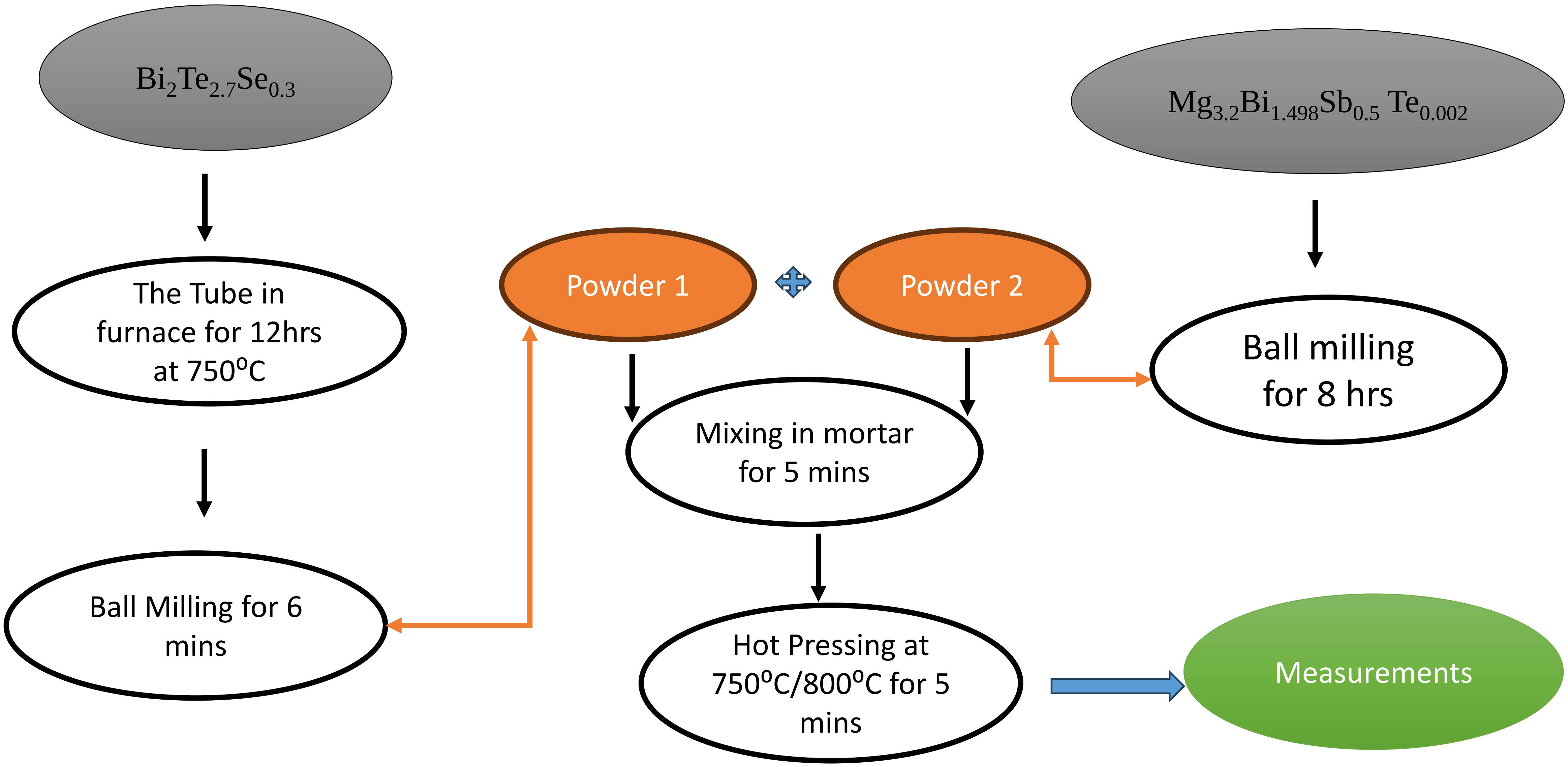


- 1% $Bi_2Te_{2.7}Se_{0.3}$
- Got p type
- ZT at 300K is 0.1 and at 500K is 0.3

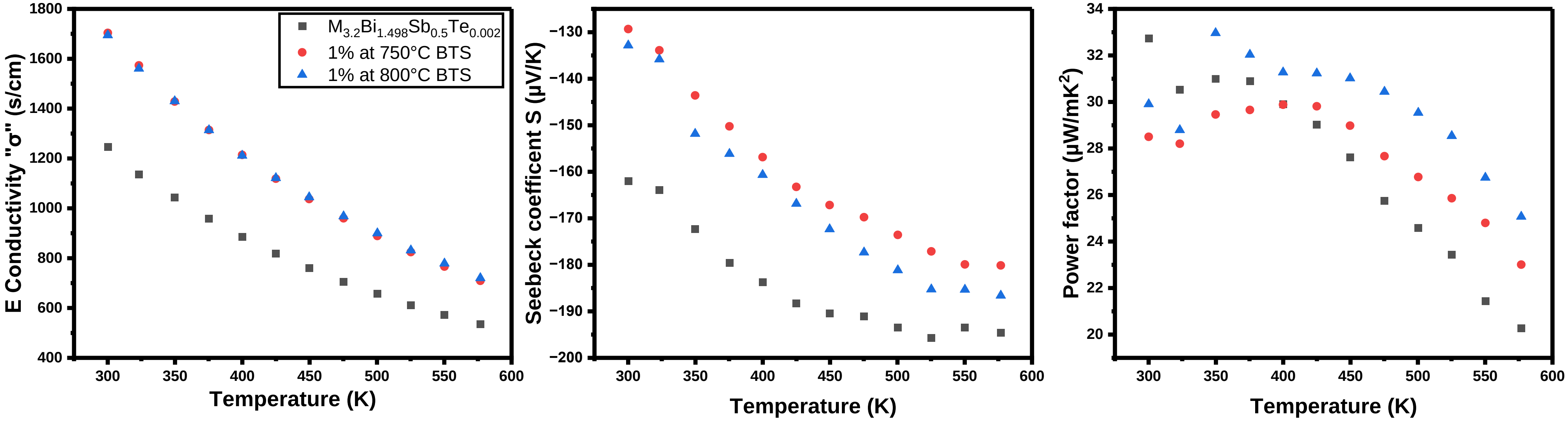
Step 1

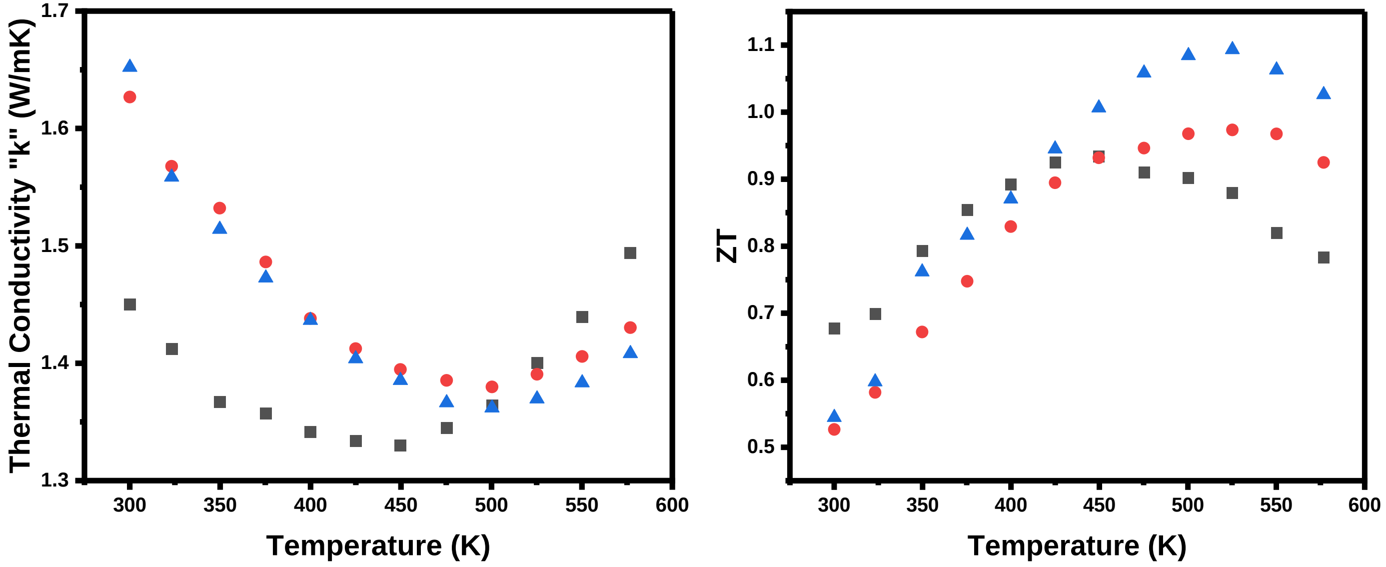
Composite Direct Mixing

Step 2



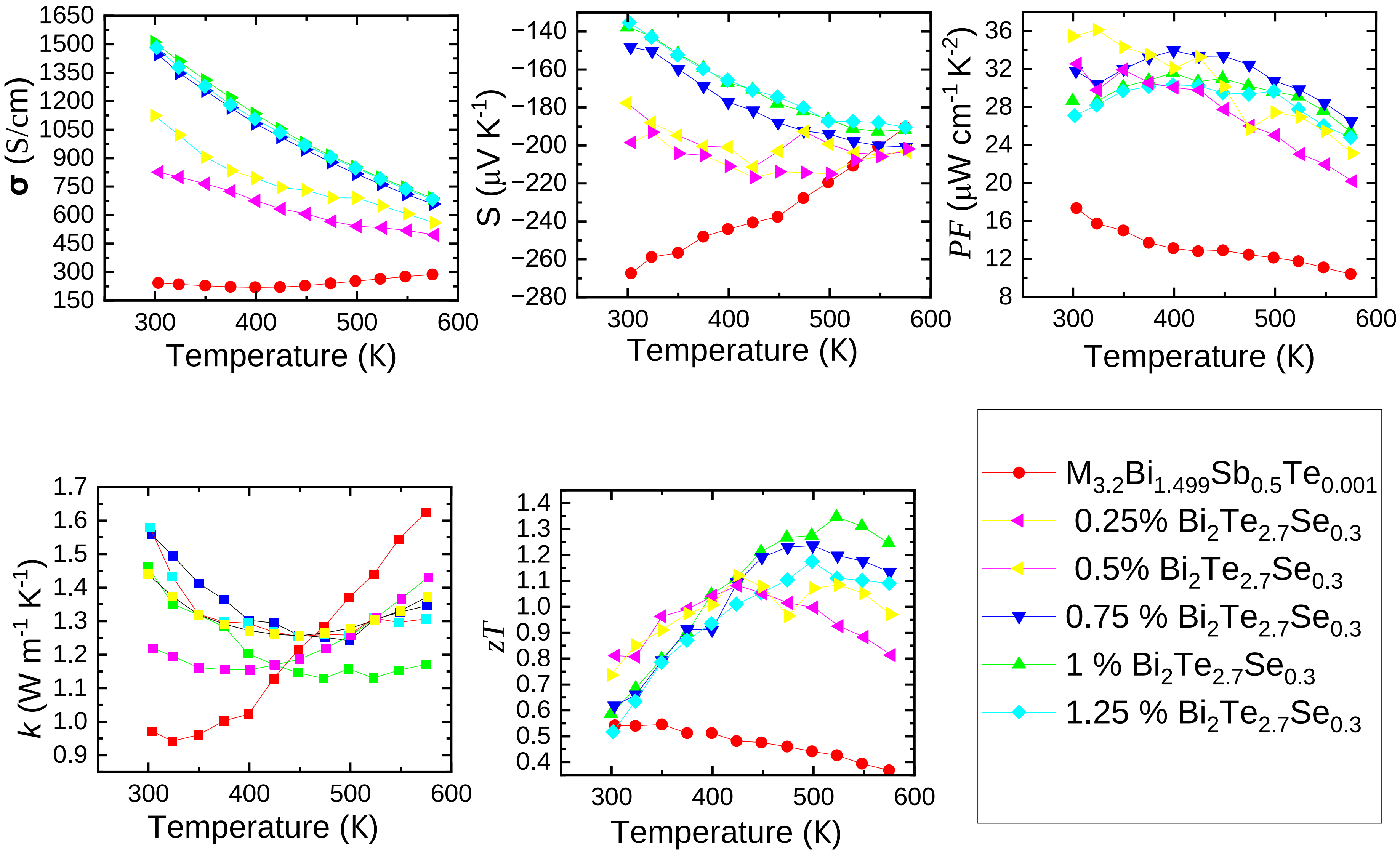
$(1\text{-}x)(Mg_{3.2}Bi_{1.498}Sb_{0.5}\ Te_{0.002}+x(Bi_2Te_{2.7}Se_{0.3})$





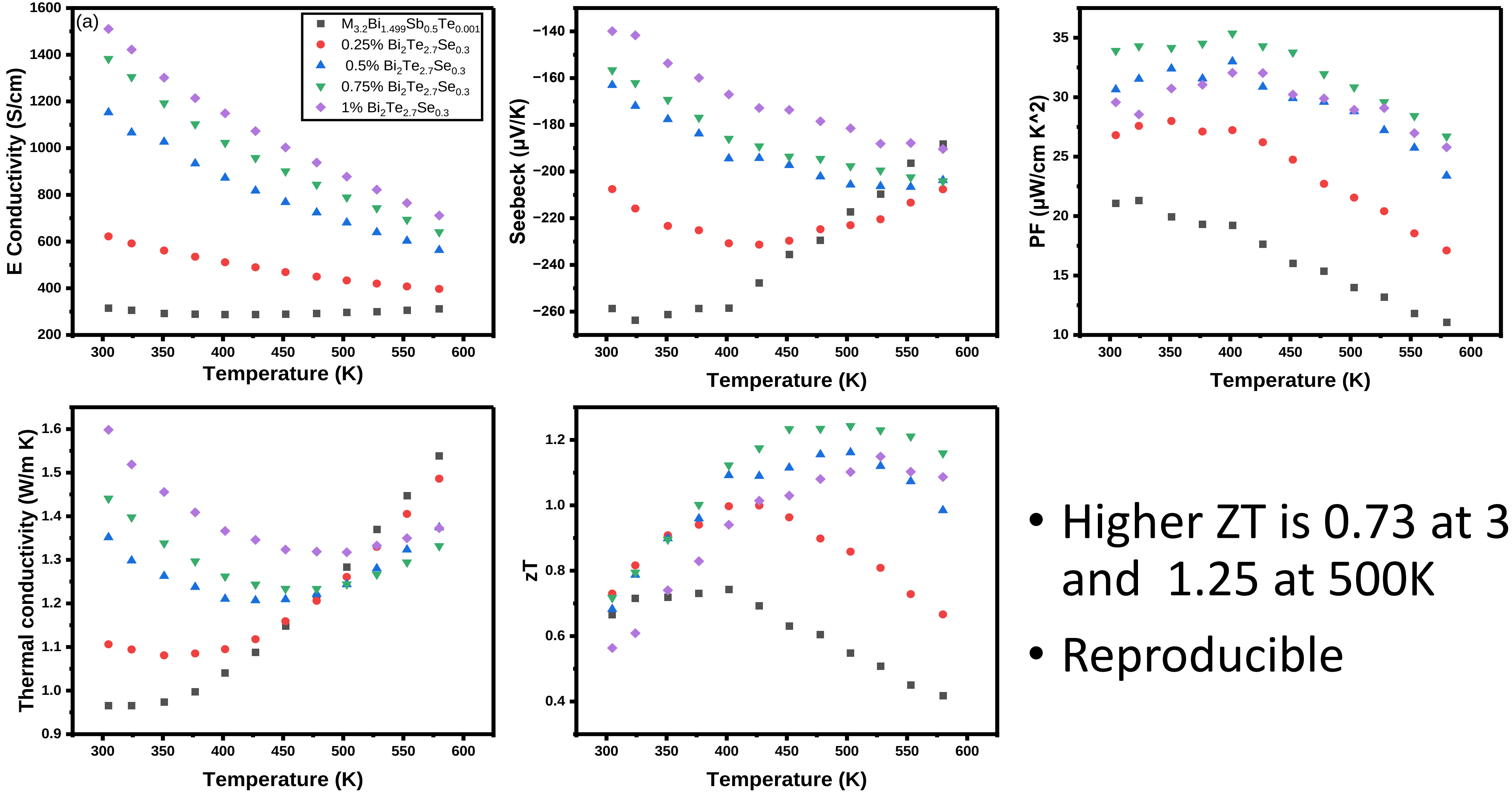
- Higher ZT at 300K is 0.54 and 500K is 1.1
- N type composite

$(1\text{-}x)(Mg_{3.2}Bi_{1.499}Sb_{0.5}\ Te_{0.001}+x(Bi_2Te_{2.7}Se_{0.3})$



- Reduce the Te amount and increase Bi
- ZT at 300K is 0.81 for 0.25% BTS and at 525K is 1.34 for 1% BTS

$(1\text{-}x)(Mg_{3.2}Bi_{1.499}Sb_{0.5}\ Te_{0.001}+x(Bi_2Te_{2.7}Se_{0.3})$



- Higher ZT is 0.73 at 300K and 1.25 at 500K
- Reproducible

Conclusion

- Successfully synthesized the Pure Compounds and reproduced the composites
- Got the N type composite by changing the synthesis process
- Increase the performance by reducing the extra dopant Te by 0.001 for medium range temperature

Work In Progress

- For $Bi_2Te_{2.7}Se_{0.3}$ confirmation I will check best composites at different temperature.
- SEM to check the morphology of composite with temperature and composition and EDS to confirm the wt%

Thanks for your Attention

Acknowledgment

- Advisor: Pro Zhifeng Ren
- Dr Shaowei Song
- Xin Xi
- Suraj Pardan
- Navmi Naik
- Haroon Khan
- Rui Shu

STRATEGIES TO ACHIEVE A HIGH FIGURE-OF-MERIT (ZT)

- To improve the electrical transport properties via optimizing n.

$$S = \frac{8\pi^2 k_B^2}{3eh^2} m * T \left(\frac{\pi}{3n}\right)^{2/3}$$

$$\sigma = {}^{1}/_{\rho} = ne\mu$$

$$\kappa_e = L\sigma T = ne\mu LT$$

- To optimizing band engineering which cause higher power factor

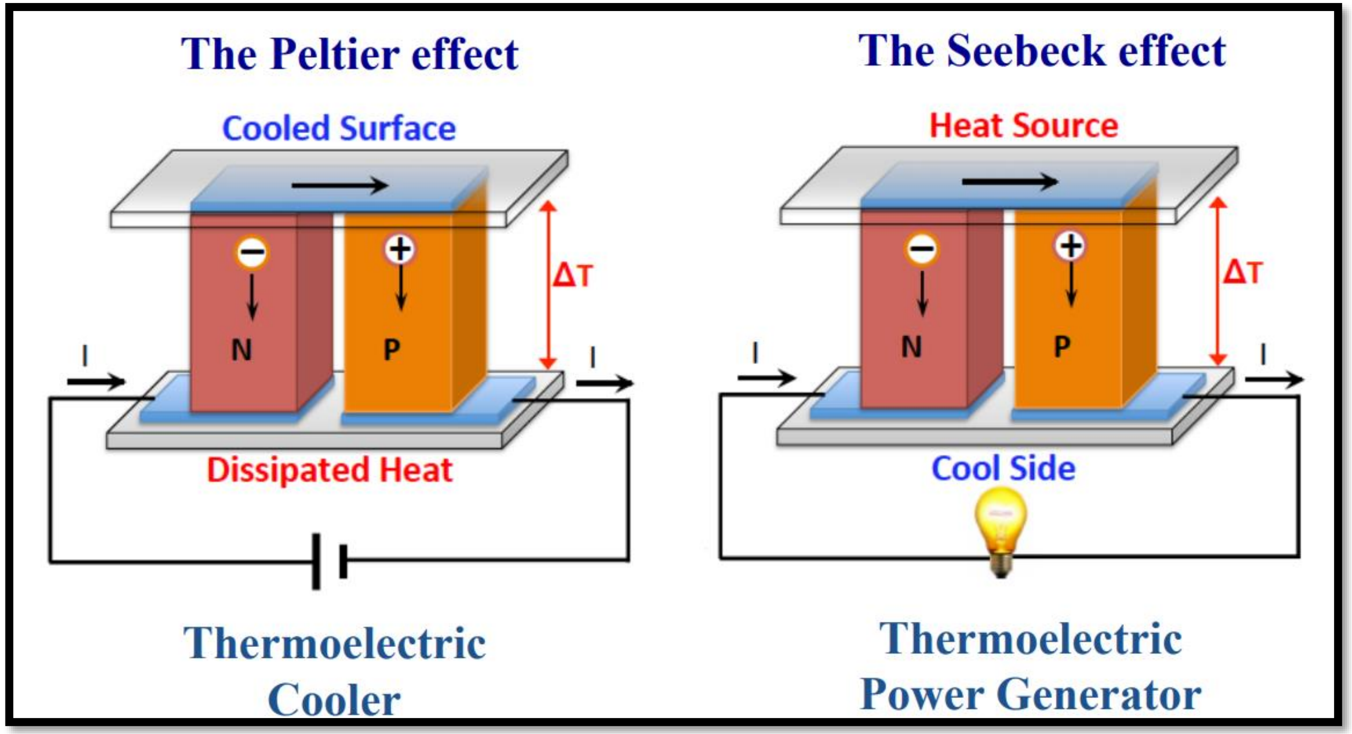
Yang, Lei (2018). *Emerging Materials for Energy Conversion and Storage*

Outline

- Introduction
- Seebeck effect and Peltier effect
- Thermoelectric Efficiency
- Types of Thermoelectric Materials(TEMs)
- Problems to enhance the efficiency of TE materials
- Applications of TE materials
- Synthesis to make high quality TE materials
- Conclusion and discussion

Thermoelectric Effect

- Used for harvesting and recovering heat which is directly converted into electrical energy using thermoelectric generators (TEGs) Conversely,
- Peltier coolers and heaters are utilized to convert electrical energy into heat energy for cooling and heating purposes



[Ssennoga Twaha, 2016]

Thermoelectric Performance

- Dimensionless figure of merit *zT*
- Where *S*, *σ*, *T*, and *κ* are the Seebeck coefficient, electrical conductivity, absolute temperature, and total thermal conductivity
- Where *k*= *k*(electron) + *k*(lattice)

Seebeck coefficient — Electrical conductivity

Material: $$zT = \frac{S^2\sigma}{k}T$$

Thermal conductivity

[Fujiwara, R, 2023]

Types of Thermoelectric Materials

Inorganic TE materials (N and P type)

- Bismuth telluride (Bi_2Te_3) and its alloys
- Lead telluride (PbTe) and its alloys
- Silicon-germanium (SiGe) alloys,
- Antimony telluride (Sb2Te3)
- Tin selenide (SnSe)
- The abundancy of tellurium (Te) in the earth's crust is only around 0.001 ppm which is less than gold 0.004ppm
- MgAgSb

Organic TE materials (N and P type)

- Organic TE materials, including polymers, carbon nanotubes (CNTs), and graphene
- Low zT values
- Advantages of being inexpensive and recyclable
- The intrinsic flexibility of organic TE materials
- In general, organic TE materials possess low thermal conductivity
- ZT value depends on the power factor

Inorganic-organic TE composites(N and P type)

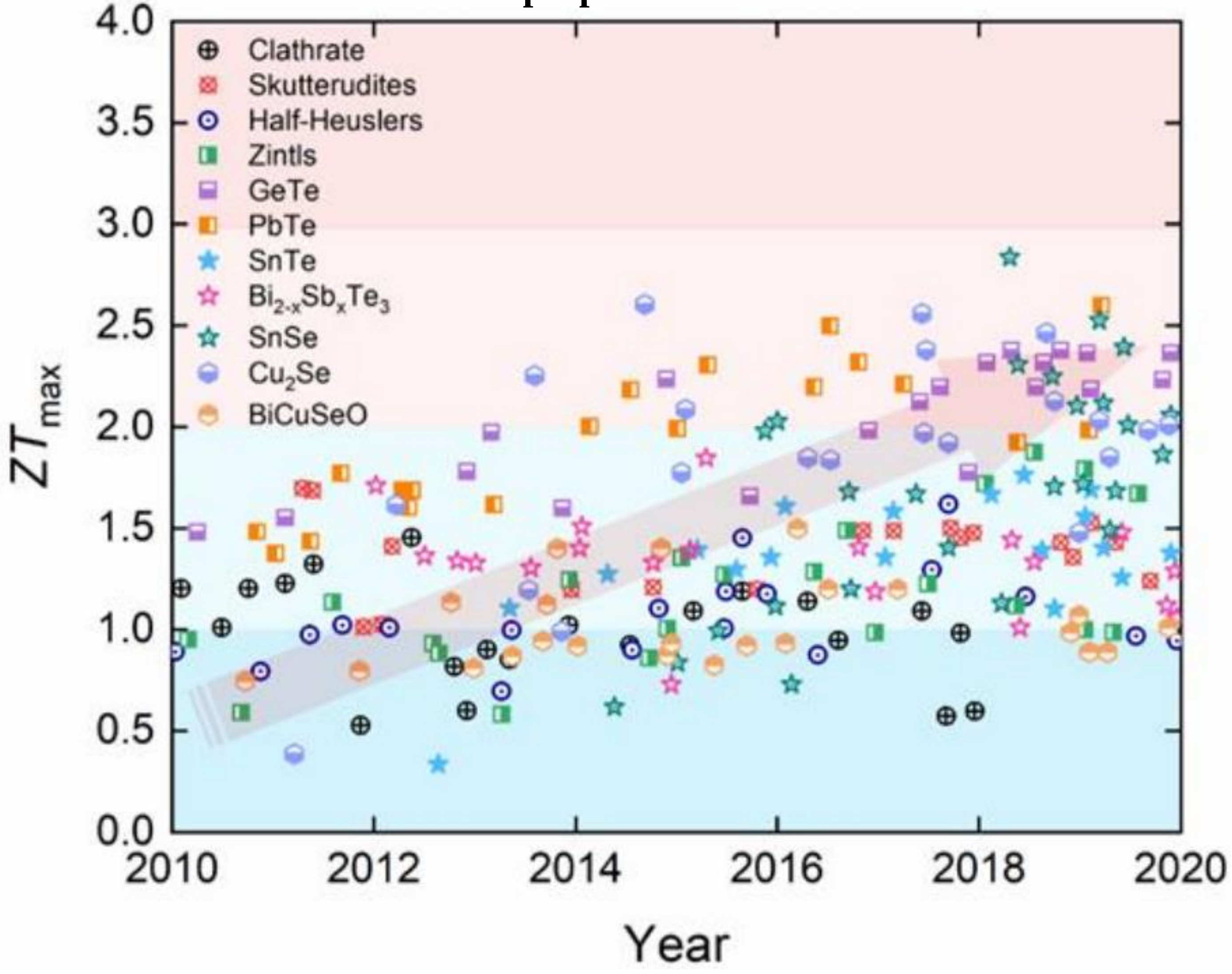
- Organic TE materials contain lower electrical conductivity and Seebeck coefficient
- Organic TE materials benefits from low thermal conductivity, low density, low cost, low environmental impacts, and good mechanical flexibility
- Achieving all these requirements in one TE material is of importance

Groups of TE materials and Performance

Present Thermoelectric material for Commercial Use

- Bismuth Telluride (Bi2Te3), 1950s
- Lead Telluride (PbTe), 1970s
- Silicon Germanium (SiGe), 1970s
- Skutterudittes, 1990s

TE properties at 300K



zT values Inorganic and organic TE materials

Inorganic TE materials (N and P type)

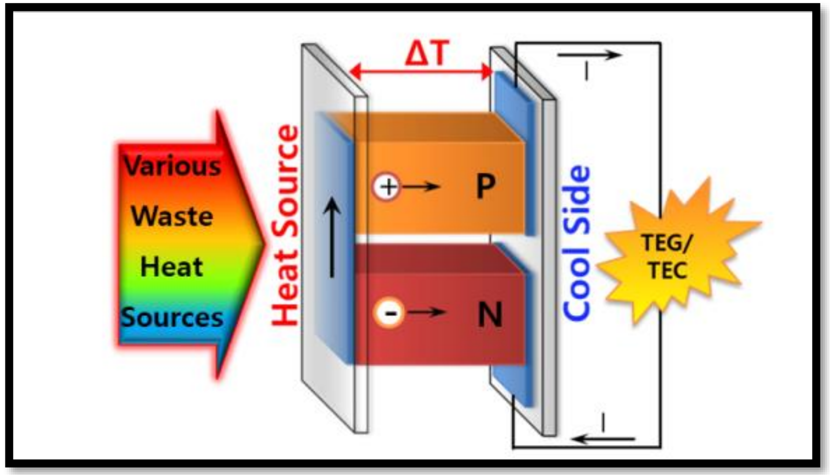
Type	TE material	α [μV/K]	σ [S/cm]	PF [μW/mK^2]	λ [W/mK]	ZT	Ref
P type	$Sb_{1.85}In_{0.15}Te_3$	124	500	-	0.9	0.27	[26]
	$Mg_{0.995}Li_{0.005}Ag_{0.97}Sb_{0.99}$	200	588	2300	0.9	0.75	[28]
	$Mg_{0.97}Zn_{0.03}Ag_{0.9}Sb_{0.95}$	85	952	690	1.25	0.28	[29]
	$MgAg_{0.97}Sb_{0.985}B_{0.005}$	255	285	1860	0.8	0.7	[31]
	$Bi_{0.38}Sb_{1.62}Te_3 + Ge_{0.5}Mn_{0.5}Te$	194	1100	43	1.28	1.22	[32]
	$CuInTe_2 + Bi_{0.4}Sb_{1.6}Te_3$	175	1250	40	1.1	1.15	[33]
	$Bi_{0.4}Sb_{1.59}Ge_{0.01}Te_3$	207	909	48	1.05	1.36	[34]
	$Cu_{0.005}Bi_{0.5}Sb_{1.495}Te_3$	150	1400	-	1	0.97	[35]
	$Bi_{0.5}Sb_{1.5}Te_{2.7}Se_{0.3}$	109	1250	-	0.96	0.48	[36]
	$Bi_{0.35}Sb_{1.65}Te_3$	270	285	-	0.9	0.8	[37]
	$Bi_{0.48}Sb_{1.52}Te_3$+0.05wt% PbTe	177	1800	56	1.85	0.9	[38]
	$Bi_{0.4}Sb_{1.6}Te_3$ alloys +5 wt% Te	155	880	21	1.4	0.48	[39]
N type	$Bi_2Te_{2.39}Se_{0.6}$	-160	1200	31	1.3	0.7	[48]
	Bi_2Se_3	-105	526	575	1.2	0.14	[49]
	$Bi_2Te_{2.7}Se_{0.3}$	-263	250	-	0.79	0.76	[50]
	$Bi_2Te_{2.7}Se_{0.3}$	-146	2250	49	2.09	0.81	[51]
	$Bi_2Te_{2.7}Se_{0.3}$ + 0.3 wt% KI	-135	1350	26	1.45	0.51	[52]
	Bi_2Te_3	-105	1600	17.5	1.65	0.33	[53]
	$Bi_2Te_{2.7}Se_{0.3}$	-168	600	1650	0.73	0.68	[54]

composites

Organic TE materials (N and P type)

TE properties of some typical polymer based TE materials at 300K

Type	TE material	α [μV/K]	σ [S/cm]	PF [μW/mK^2]	Ref
P type	PEDOT:PSS films treated with H_2SO_4 and NaOH	39.2	2170	334	[67]
	PDPP3T doped with 6mM FeCl3/nitromethane	226	55	276	[68]
	PEDOT:S-PHE films	40	400	7.9	[69]
	PBTTT exposed to FTS vapor	33	1000	110	[70]
	PDTDE12 doped with F4TCNQ	80	75	20	[71]
	PDTDE12 doped with F4TCNQ	30	120	10	[72]
	PBDT-TT-TEO doped with F4TCNQ	190	1.3e-4	0.05	[73]
	C8TBT	60	2.2	1	[74]
	PEDOT:PSS post treated with TFMS–MeOH	21.9	2980	143	[75]
N type	FBDPPV doped with $(N\text{-}DMBI)_2$	-80	7.2	7	[76]
	PCBM doped with AOB and N-DMBI	-500	2	1	[77]
	P(PymPh) doped with NaNap	-16.4	18	0.485	[78]
	N-DMBI doped with A-DCV-DPPTT	-575	3.2	110	[79]
	PDPF doped with 5wt% N-DMBI	-235	1.3	4.65	[80]



ΔT
Various
Waste
Heat
Sources
Heat Source
P
N
Cool Side
TEG/
TEC
I
I

Types of Thermoelctric Materials(TE)

- **There are three types of TE materials**

Inorganic TE materials
(N and P type)

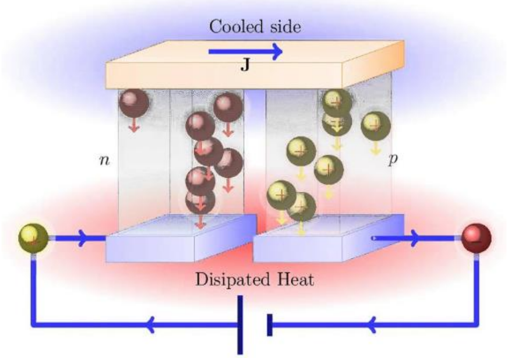
Organic-Inorganic TE materials (N and P type)

Organic TE materials
(N and P type)

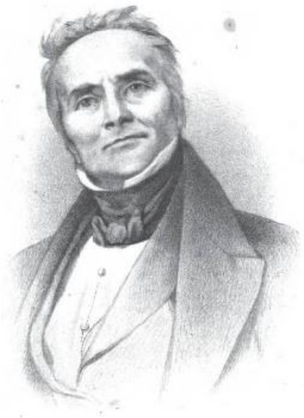
History of Thermoelectric (TE)

- Thermoelectric(TE) materials and devices, convert the direct energy between heat and electricity.

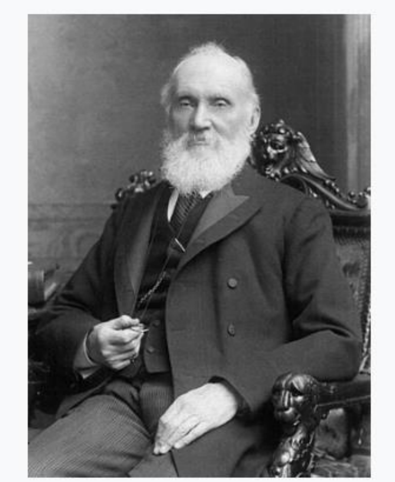
- First TE effect in 1821-3 by Thomas seebeck
- 1834 J A. Peltier
- 20 years later 1854 Willium Thomson(Kelvin Relationship)



Thomas Seebeck



Jean Charles A. Peltier



Thermoelectrics.matsci.northwestern.edu/thermoelectrics/history.html