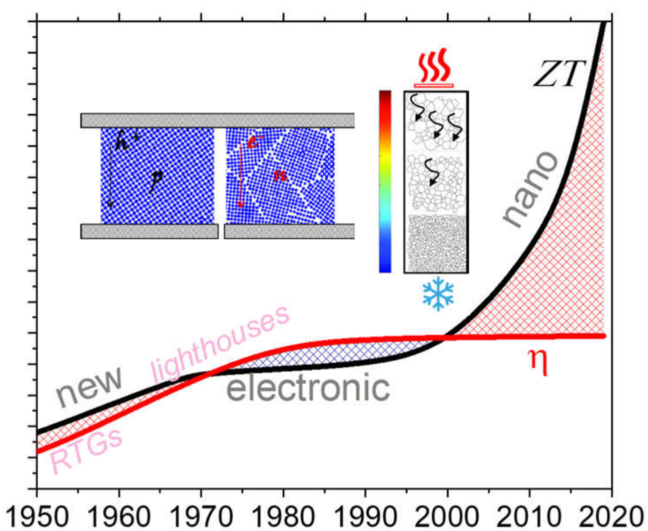
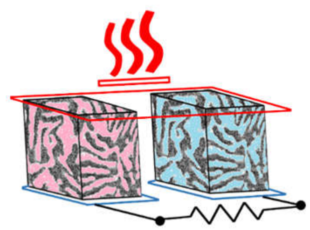
Thermal energy conversion and storage (thermoelectrics)





Diffusion
Oxidation
Coarsening
Sublimation
Phase transition
CTE matching
Mechanical properties

TRL		
	9	Commercialized
	8	Pre-production
	7	Field Test
	6	Prototype
	5	Bench / Lab Testing
	4	Detailed Design
	3	Preliminary Design
	2	Conceptual Design
	1	Basic Concept

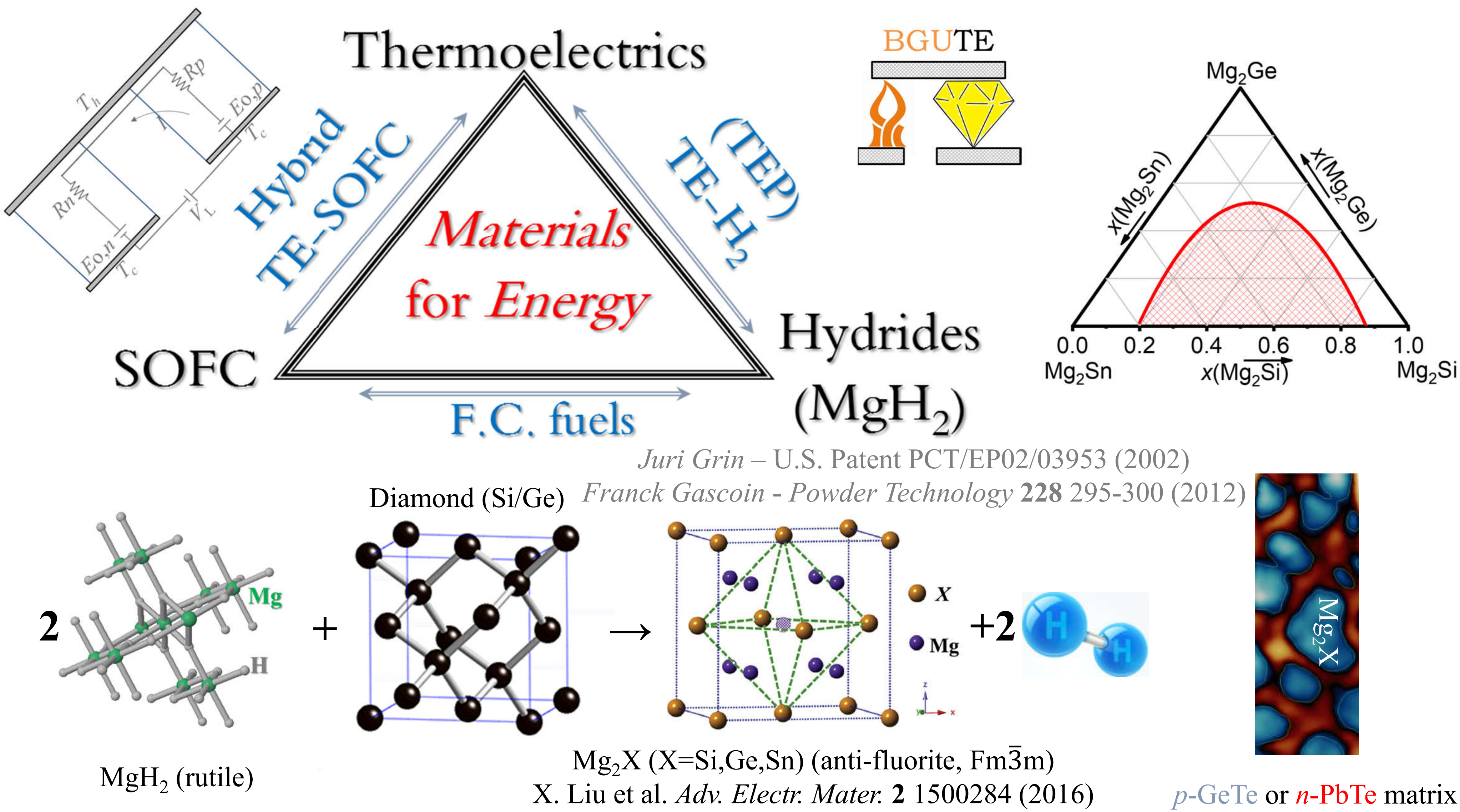
Presented by:

Prof. Yaniv Gelbstein

The Samuel Ayrton Chair in Metallurgy, Head of the Department of Materials Engineering

Ben-Gurion University of the Negev

Dutch Israeli renewable energy conversion mini symposium, ZOOM, Jan. 13 (2021)

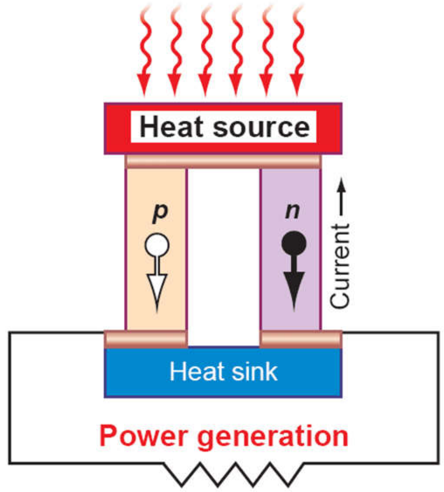


Thermoelectrics
SOFC
Hydrides
(MgH2)
Materials
for Energy
Hybrid
TE-SOFC
(TEP)
TE-H2
F.C. fuels
Th
Rp
Eo,p
Tc
Rn
VL
Eo,n
Tc
BGUTE
Mg2Ge
x(Mg2Sn)
x(Mg2Ge)
0.0
0.2
0.4
0.6
0.8
1.0
Mg2Sn
x(Mg2Si)
Mg2Si
Juri Grin – U.S. Patent PCT/EP02/03953 (2002)
Franck Gascoin - Powder Technology 228 295-300 (2012)
Diamond (Si/Ge)
2
Mg
H
+
→
X
Mg
+2
H
H
Mg2X
MgH2 (rutile)
Mg2X (X=Si,Ge,Sn) (anti-fluorite, Fm3̄m)
X. Liu et al. Adv. Electr. Mater. 2 1500284 (2016)
p-GeTe or n-PbTe matrix

Power Generation

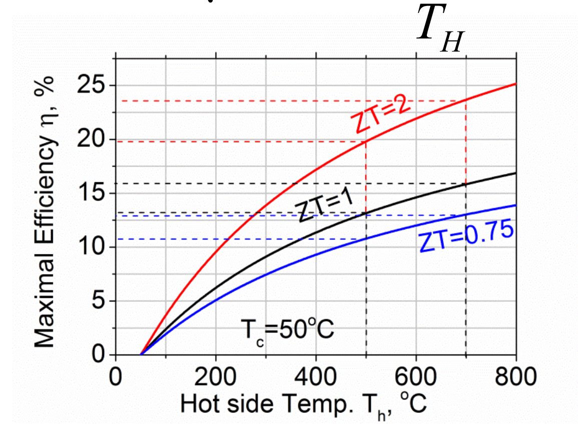
$$Z=\alpha^2/\kappa\rho$$

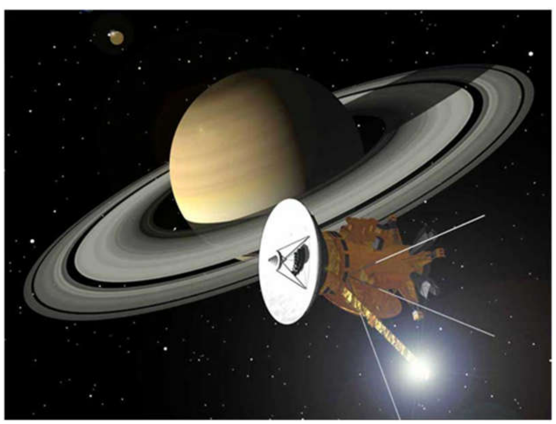
$$\eta_{opt} = \frac{\Delta T}{T_H}\frac{\left(\sqrt{1+Z\overline{T}}-1\right)}{\sqrt{1+Z\overline{T}}+\frac{T_C}{T_H}}$$

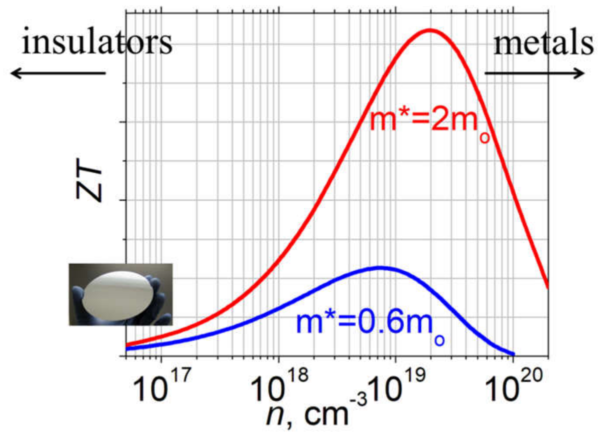


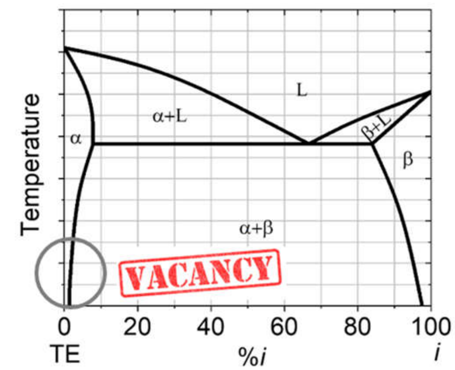
$$V = \alpha \cdot \left(T_h - T_c\right)$$

$$\kappa = \kappa_L + \kappa_e$$



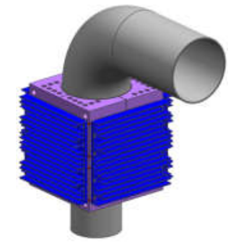




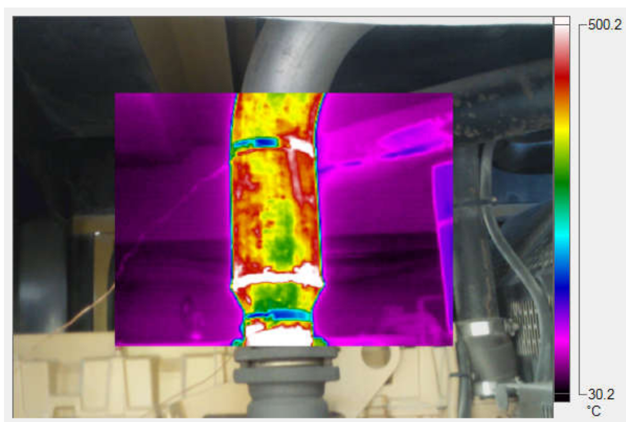


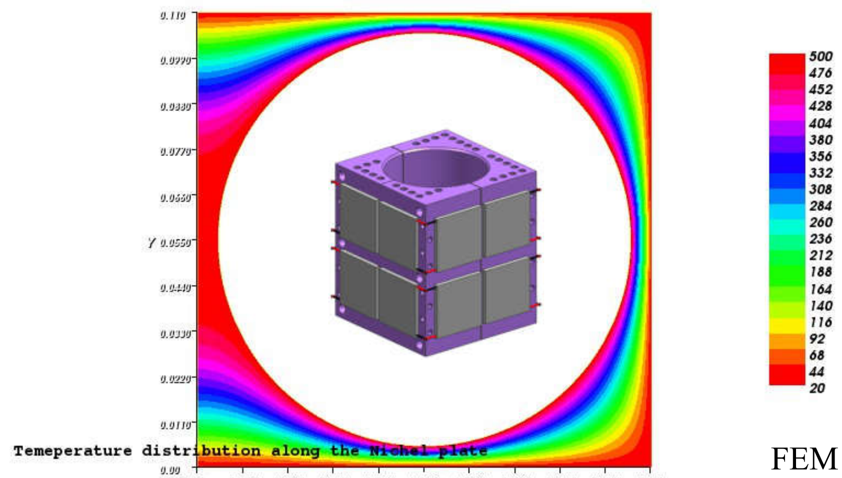
NASA deep space – Cassini (www.nasa.gov)

CATERPILLAR® ZOKO



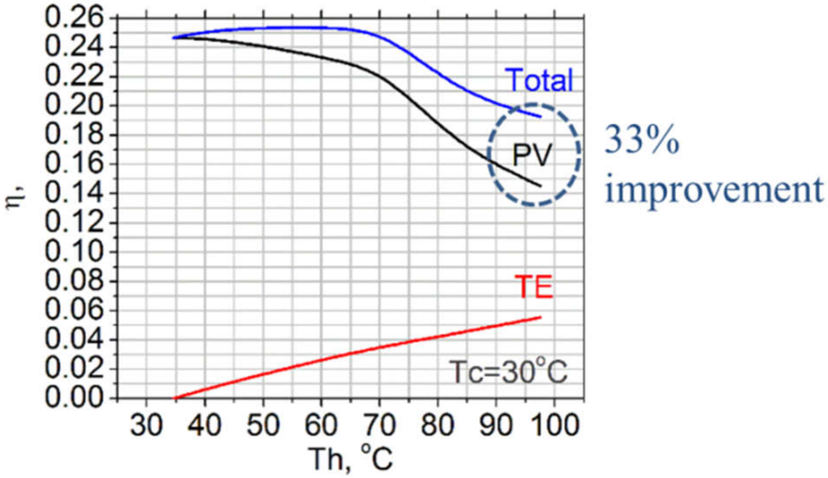
400°C @ 250kW load

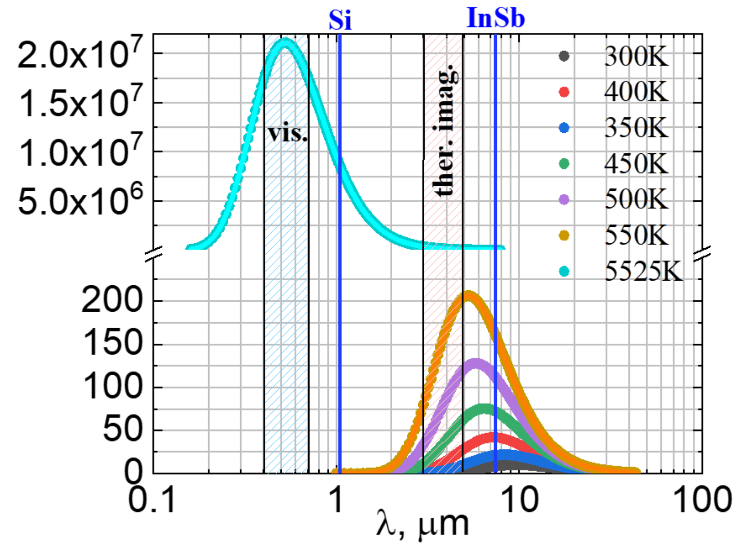


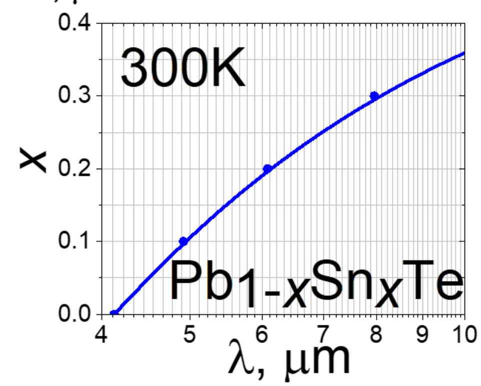


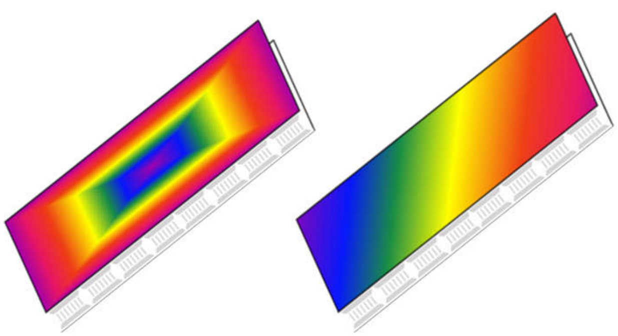
FEM

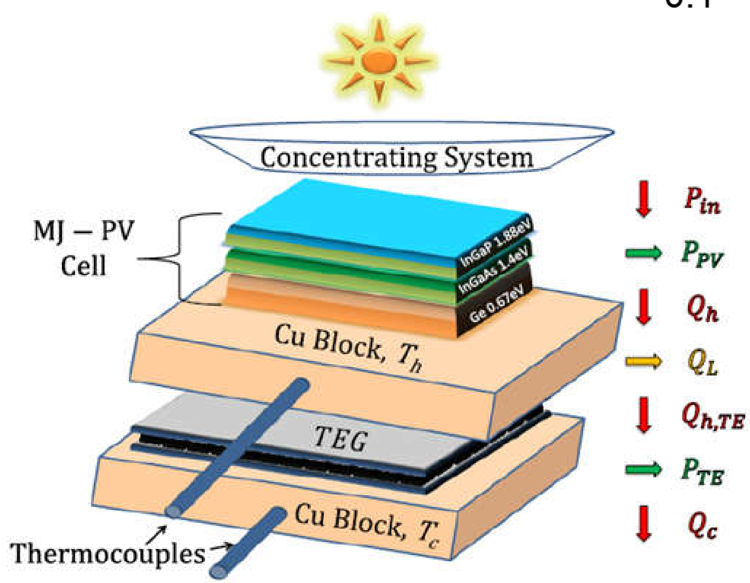
PV-TE applications





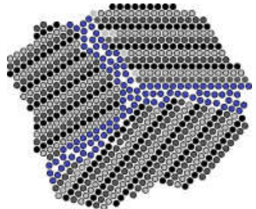




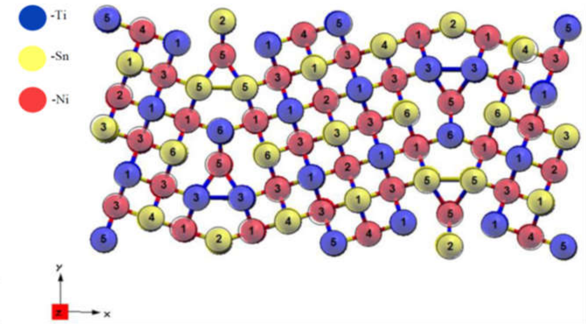


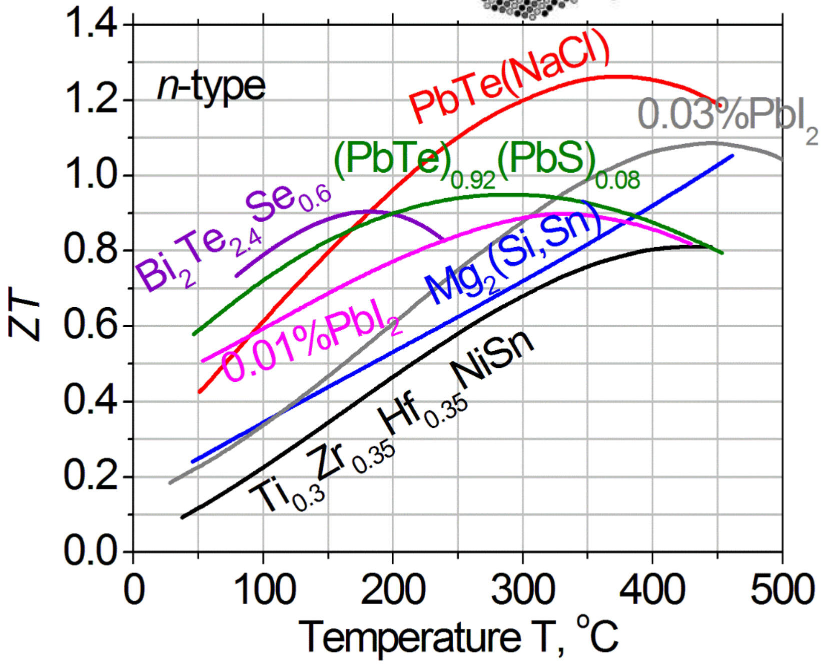
J.Appl.Phys. **118** 115104 (2015)

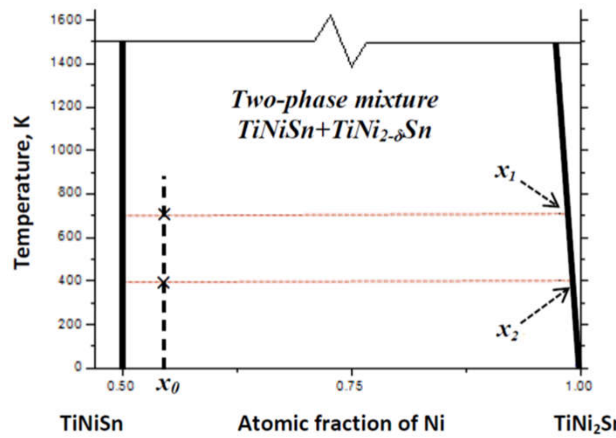
MarTEnergy

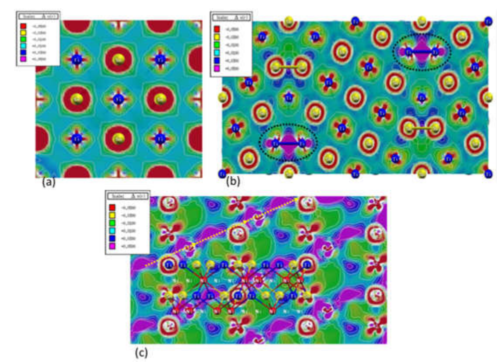


G.B.
+
Sn segregation









HH-

Journal of Materials Research **26**(15) 1919-1924 (2011)

Journal of Electronic Materials **42**(7) 1340-1345 (2013)

Journal of Solid State Chemistry **203** 247-254 (2013)

Journal of Electronic Materials **43**(6) 1976-1982 (2014)

Physical Chemistry and Chemical Physics **16** 20023 (2014)

PbTe-PbS-

Adv. Energy Mater. **5**(11) 1500272 (2015)

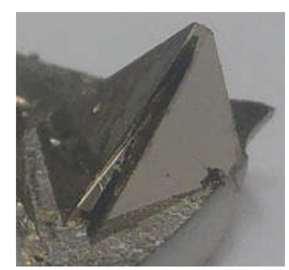
Silicides-

Journal of Electronic Materials **41**(6) 1504-1508 (2012)

Journal of Electronic Materials **42**(7) 1926-1931 (2013)

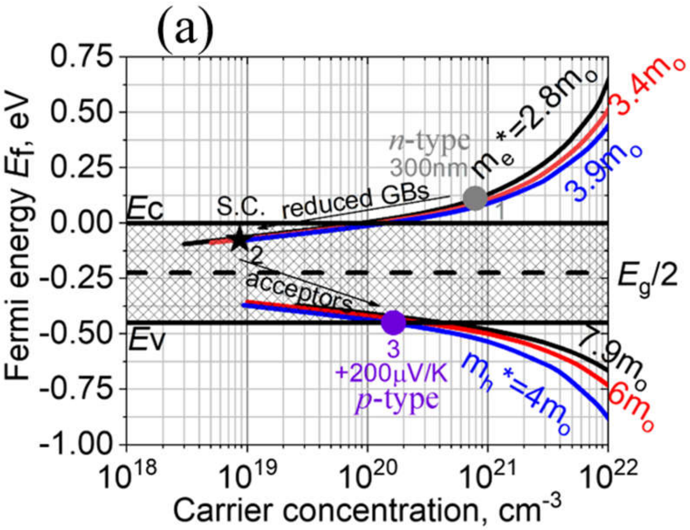
Journal of Nanomaterials **701268** (2013)

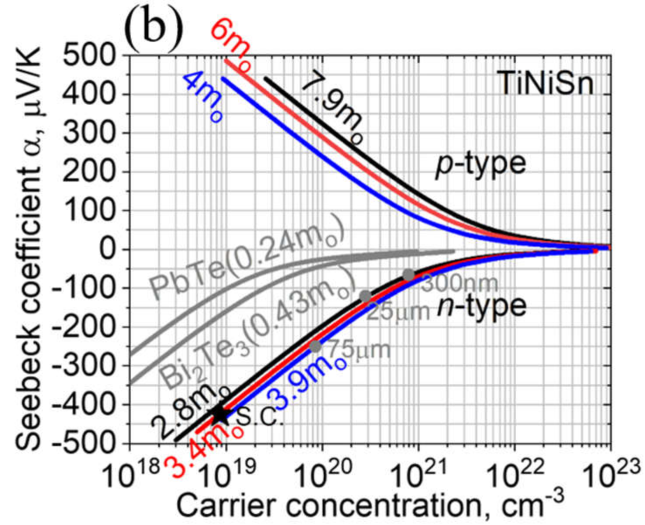
Journal of Electronic Materials **43**(6) 1703-1711 (2014)

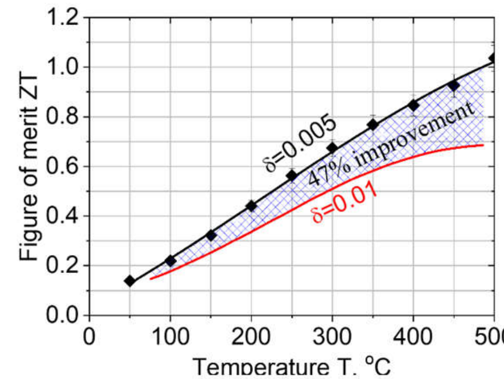


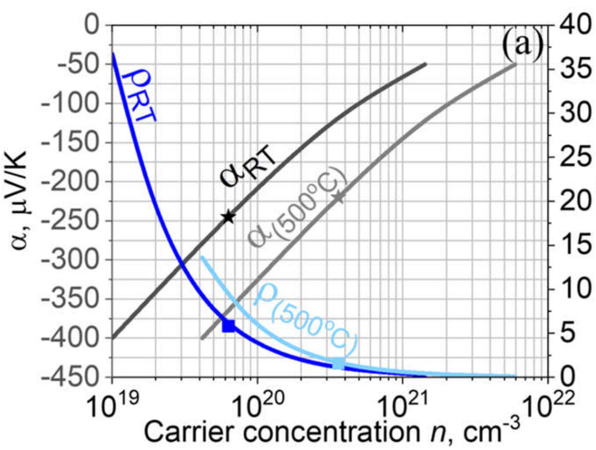
Half-Heusler – TiNiSn & $Ti_{0.3}Zr_{0.35}Hf_{0.35}Ni_{1+\delta}Sn$

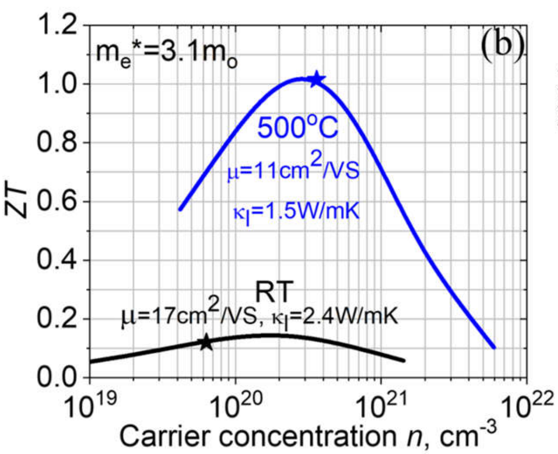
JAP **126** 085110 (2019)

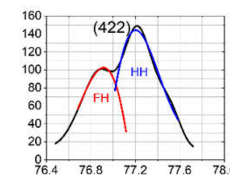


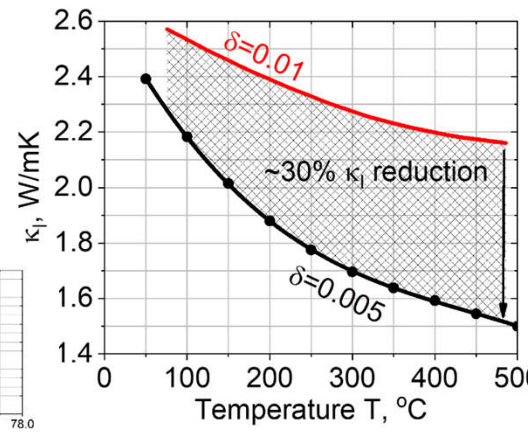


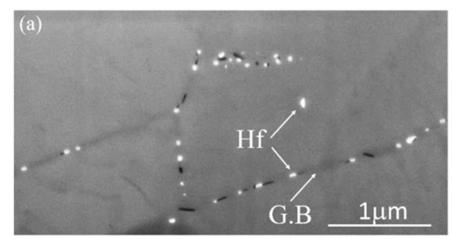


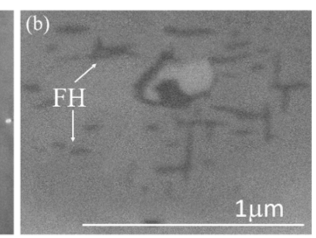




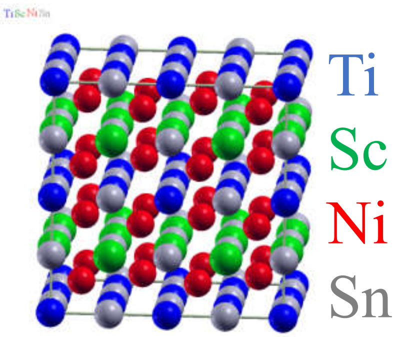




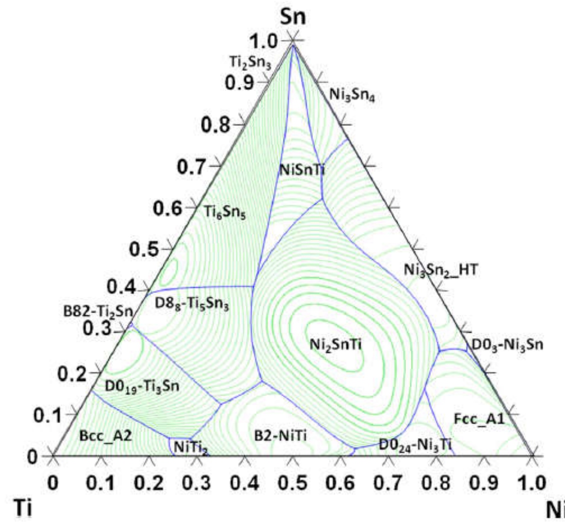




Journal of Alloys and Compounds **781** 1132-1138 (2019)



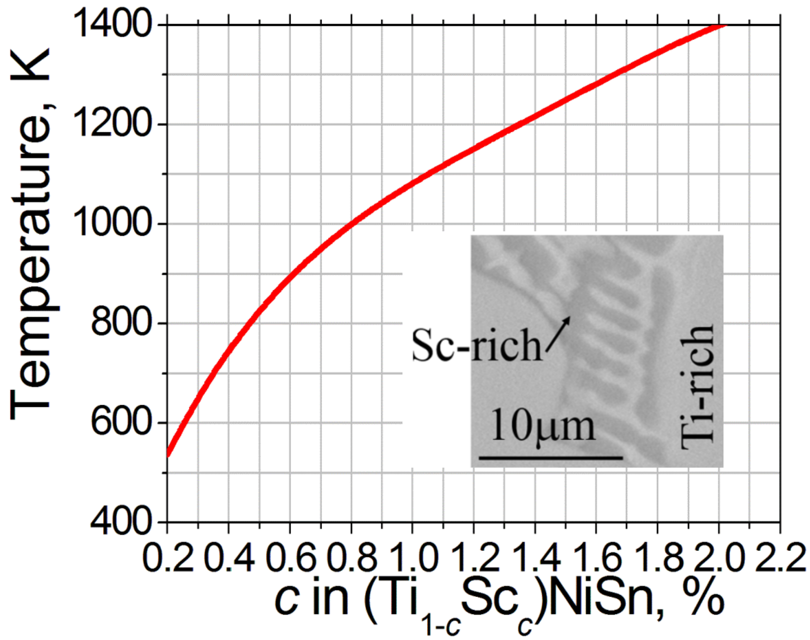
p-type HH $(Ti_{1-c}Sc_c)NiSn$

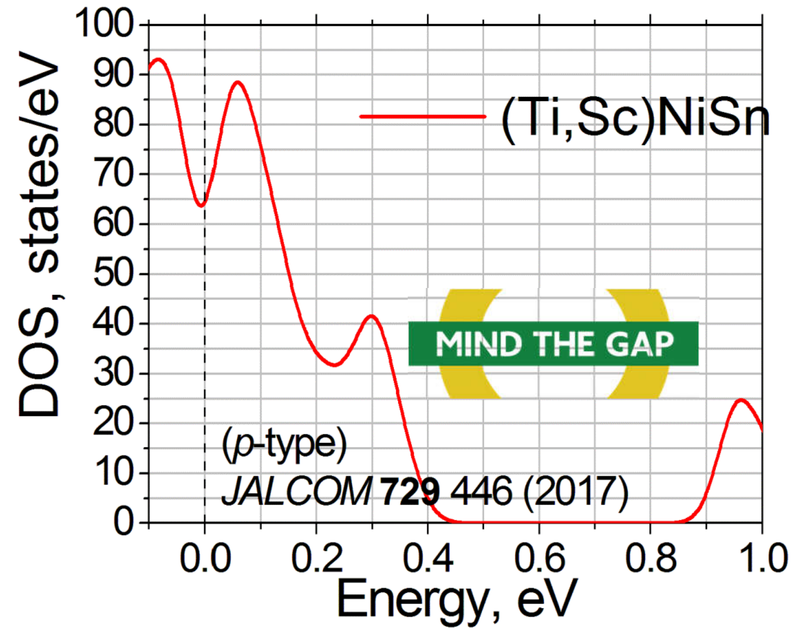


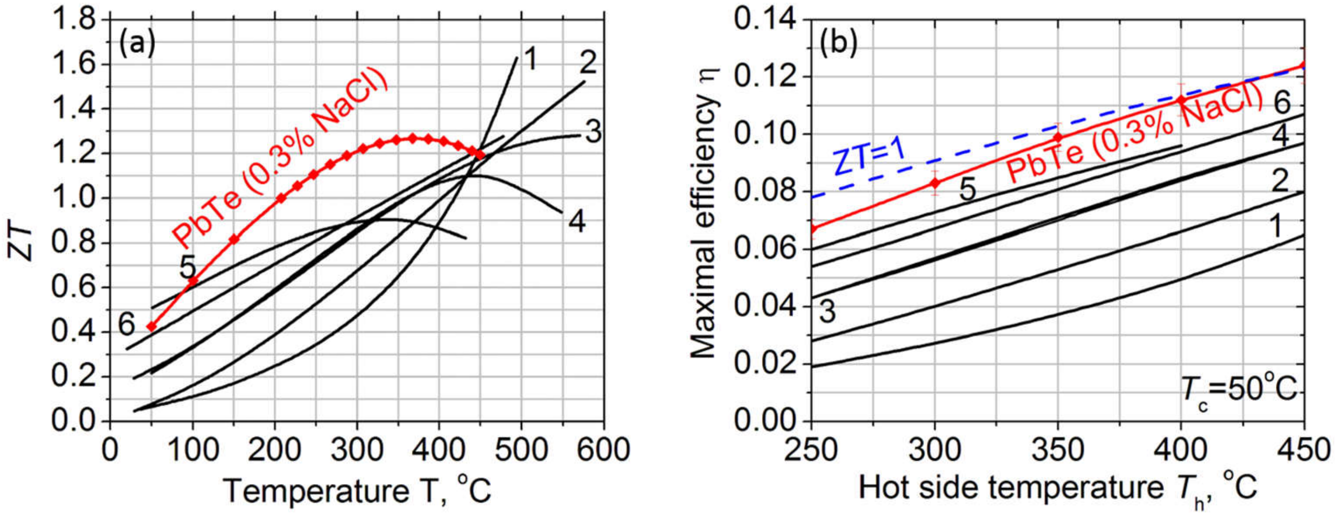
Solidification sequence:
FH→HH,Sn_5Ti_6, minority phases→HH

Effects of Fe (acceptor) & Cu (donor) in TiNiSn -Intermetallics **98** 154-160 (2018)

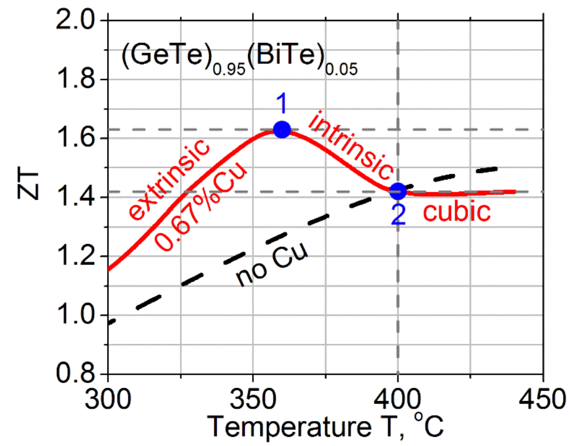
p-type $(Ti_{1-c}Al_c)NiSn$ – *PCCP* **21** 7524 (2019) & PCCP **22**(3) 1566 (2020)



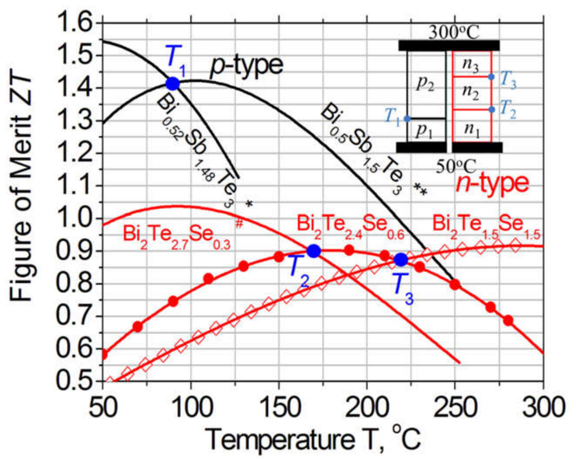


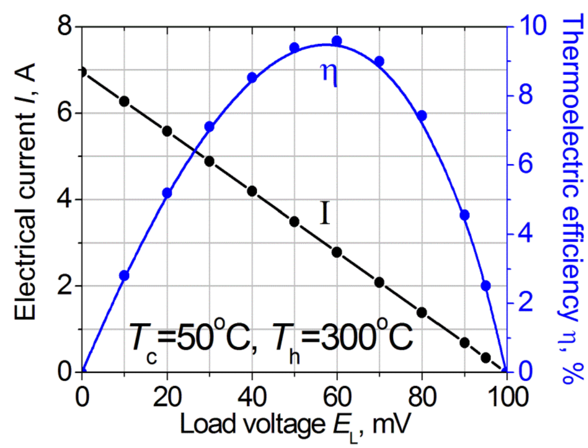


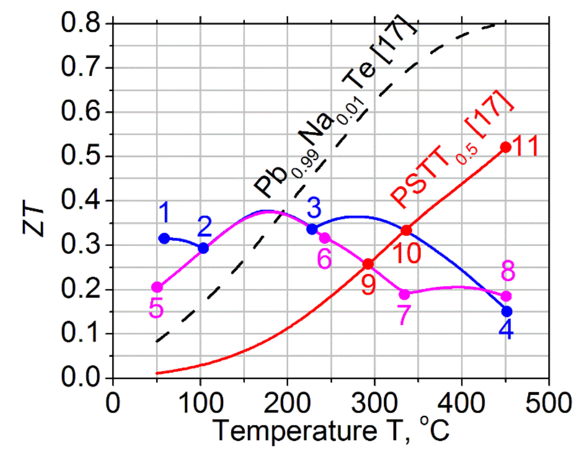
J. Mater. Chem. C **3** 9559-9564 (2015), J. Sol. Stat. Chem. **240** 91 (2016)



Adv. Electron. Mater. **1** 1500228 (2015)
J.Appl.Phys. **120** (3) 035102 (2016)

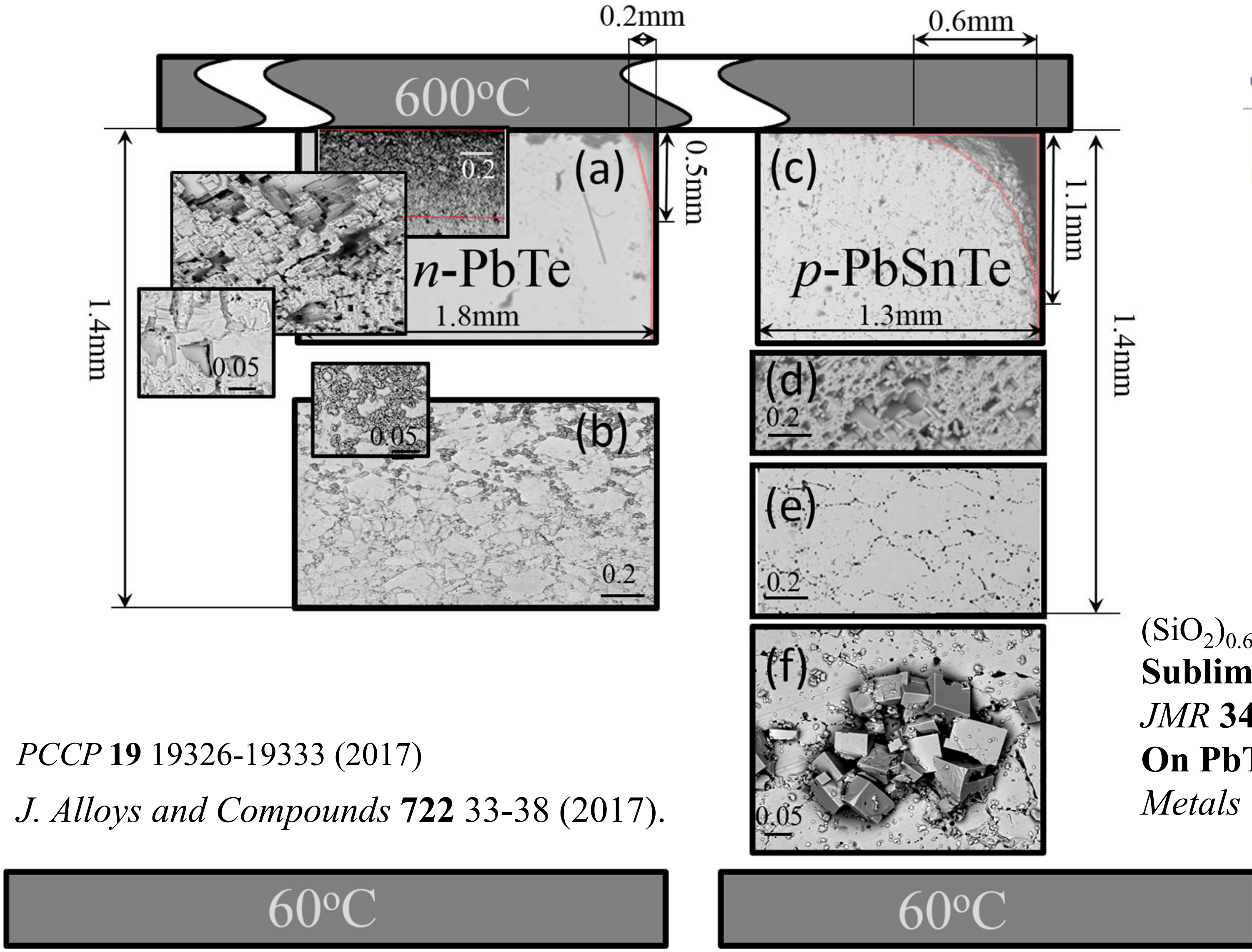


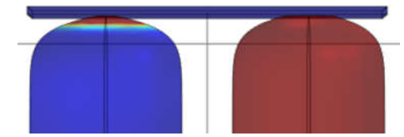




J.Alloys and Compounds **679** 196-201 (2016), *PCCP* **20**(6) 4092 (2018)

J.Appl.Phys. **118** 065102 (2015)
J.Appl.Phys. **120** (5) 055104 (2016)





PCCP **19** 19326-19333 (2017)

J. Alloys and Compounds **722** 33-38 (2017).

$(SiO_2)_{0.68}(PbO)_{0.3}(Na_2O)_{0.01}(B_2O_3)_{0.01}$

Sublimation coating-

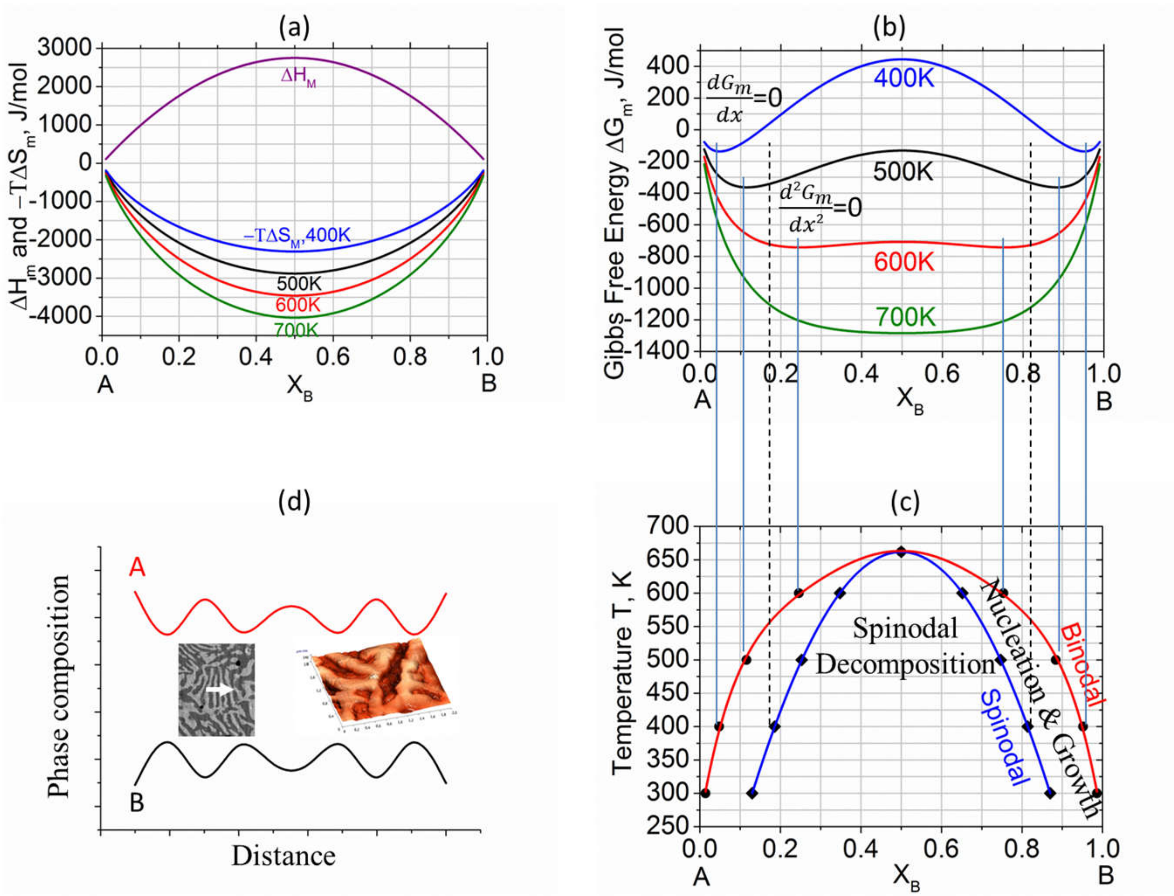
JMR **34**(20) 3563-3572 (2019)

On PbTe-

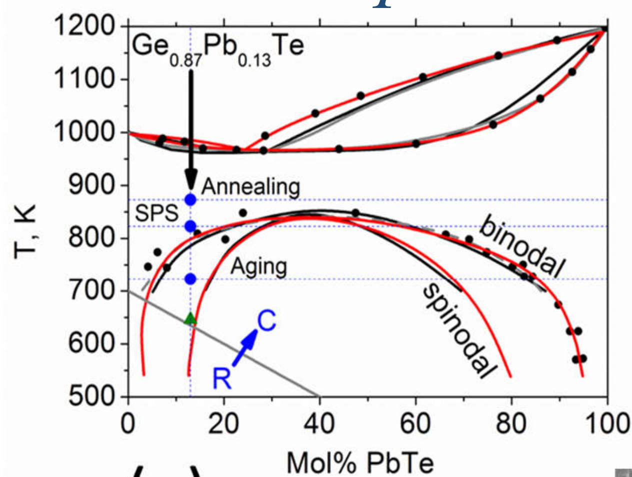
Metals **10** 284 (2020)

Phase Separation - I

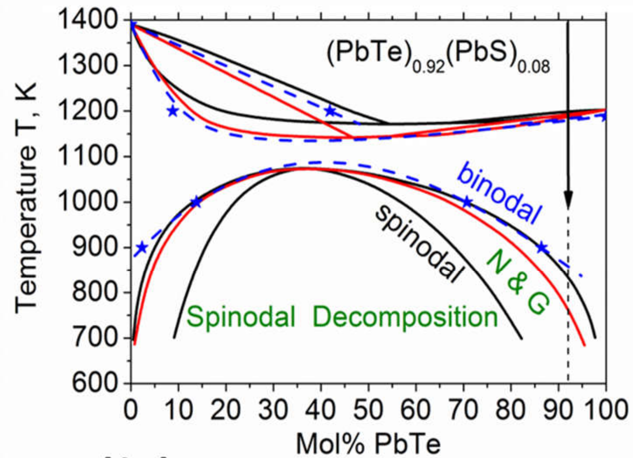
$$\Delta G_m = \Delta H_m - T\Delta S_m = \omega \cdot x \cdot (1-x) + T \cdot R \cdot [(1-x) \cdot ln(1-x) + x \cdot ln(x)]$$

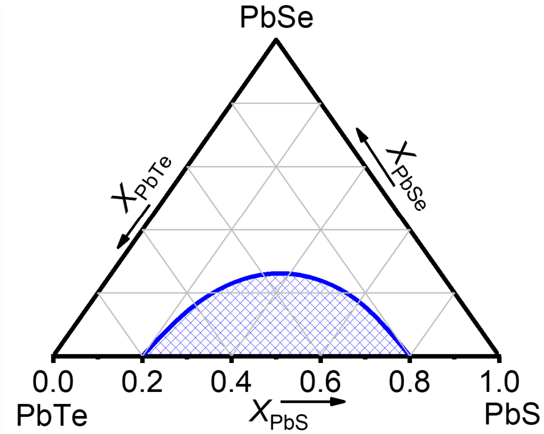


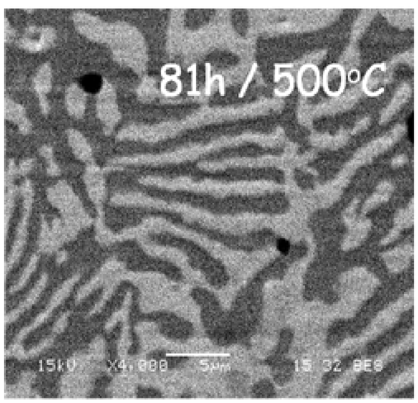
Phase Separation - II



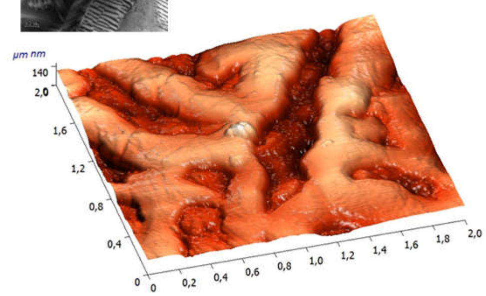
(a)



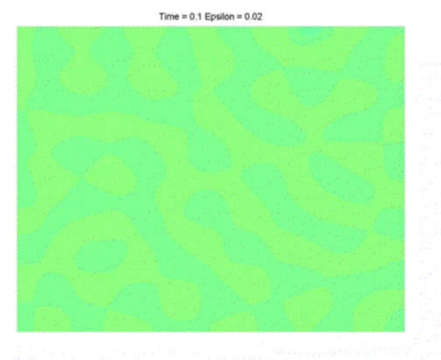




(b)

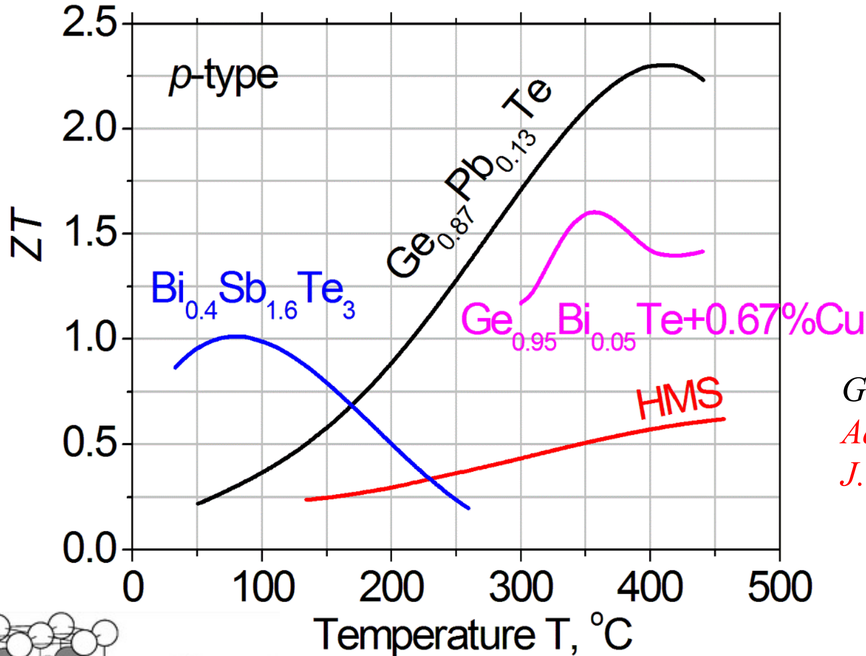


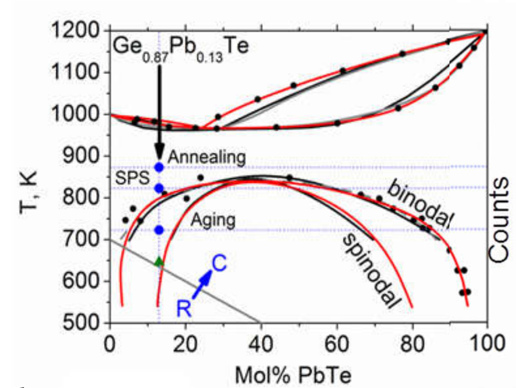
Cahn-Hilliard equation→

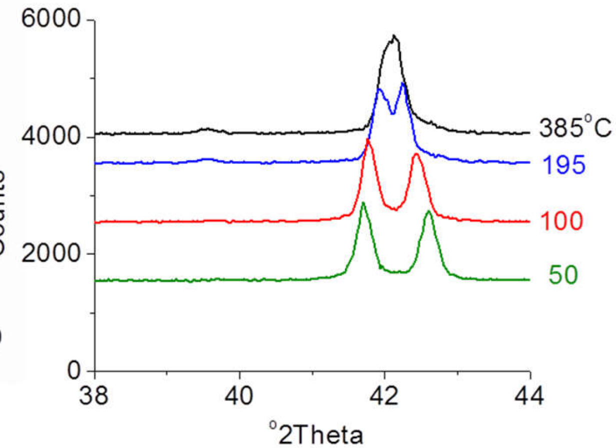


Evelyn Sander and Thomas Wanner, Monte-Carlo simulation

(a) Yaniv Gelbstein, Mercouri Kanatzidis et al., *Adv. Energy Mater.* **3** 815-820 (2013)
(b) John Androulakis et al., *J. Am. Chem. Soc.* **129** 9780-9788 (2007)



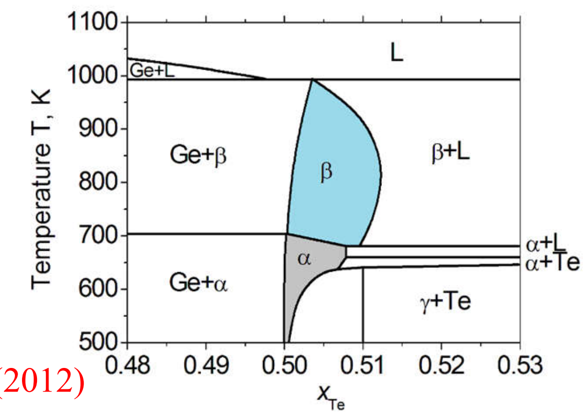


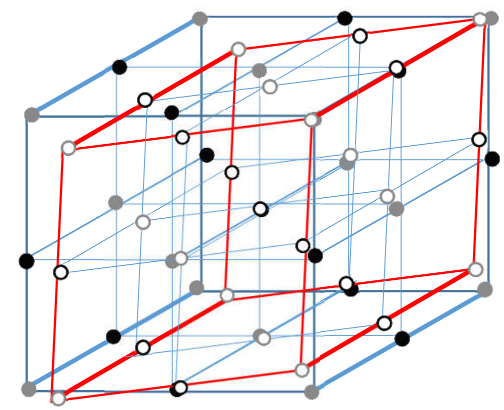


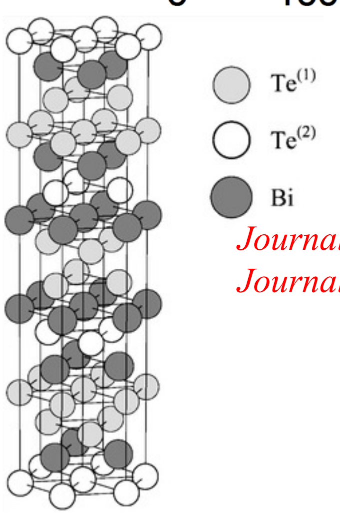
Ge$_x$Pb$_{1-x}$Te-

Adv. Energy Mater. **3** 815–820 (2013)

J. Am. Chem. Soc **136** 11412-11419 (2014)







Bi$_2$Te$_3$-

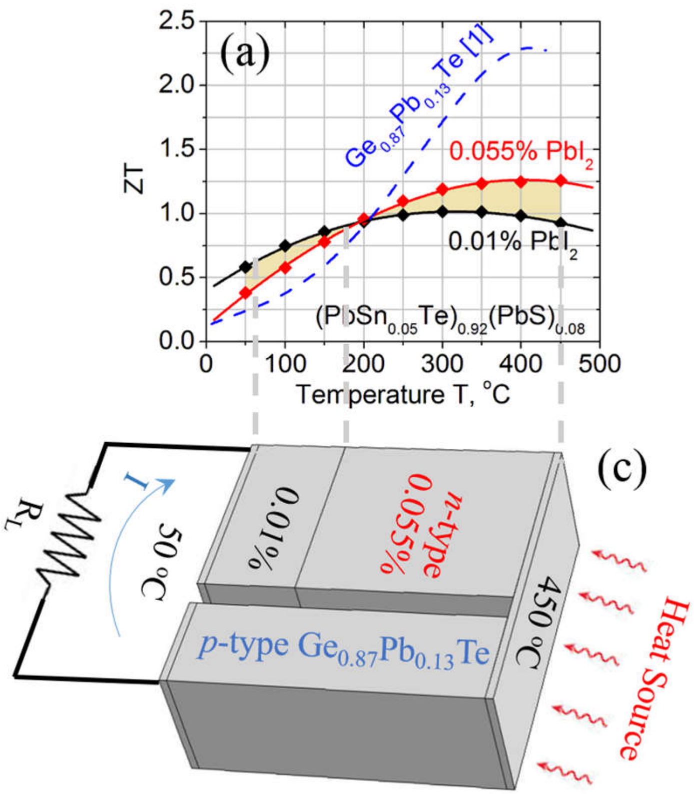
Journal of Applied Physics **101**, 113707 (2007)

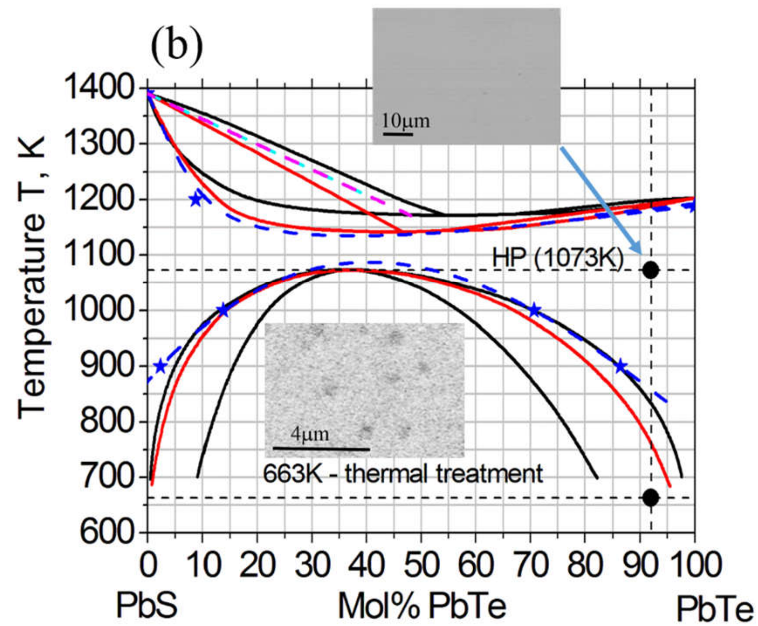
Journal of Electronic Materials **41**(6), 1546-1553 (2012)

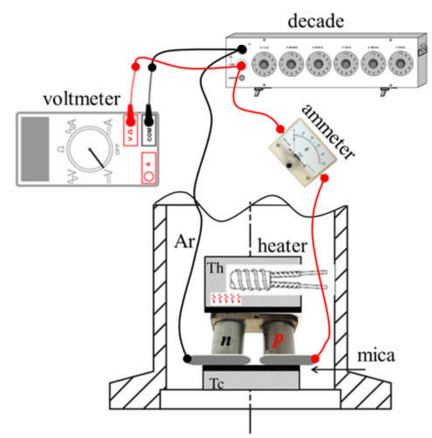
GeTe-

Phys.Stat.Sol. (RRL) **1**(6) 232-234(2007), *Powder Diffraction* **23**(2) 137(2008), *JEMS* **38**(7) 1478(2009), *Journal of Crystal Growth* **311** 4289(2009), *Chemistry of Materials* **22**(3) 1054 (2010), *JEMS* **39**(9) 2049,2165(2010), *Scripta Materialia* **62**(2) 89 (2009), *J. Phys. Chem. C* **114** 13126(2010), *J. Alloys and Compounds* **526** 31(2012), *JEMS* **42**(7) 1542(2013).

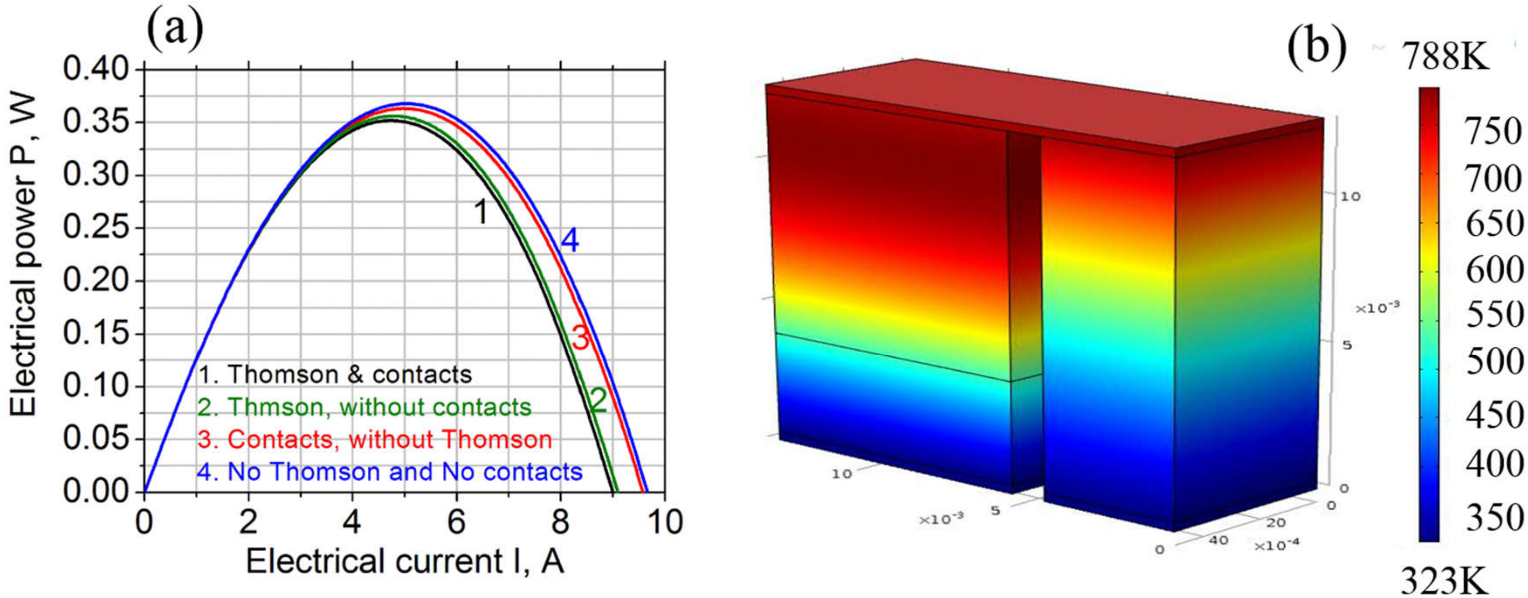
GePbTe-PbTe/PbS

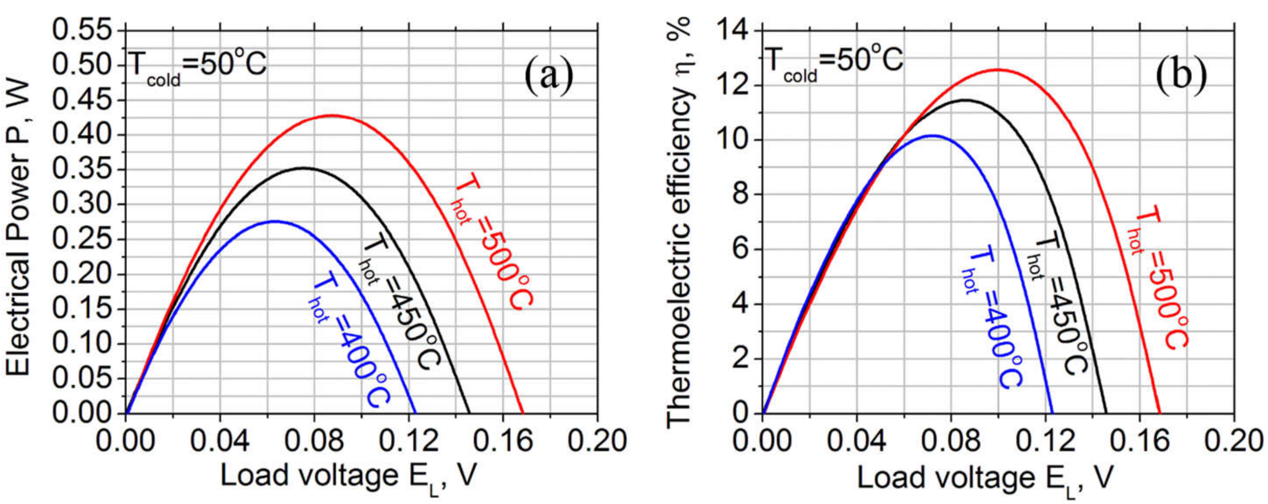






Adv. Energy Mater. **1500272** (2015)
Journal of Solid State Chemistry **241** 79-85 (2016)



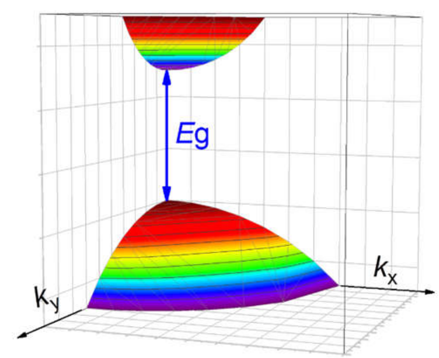


Adv. Energy Mater. **1500272** (2015)

Conclusions-

Practical TE design considerations should include:

- GB effects on **electronic** and phonon characteristics.
- Nano stabilization at the operating temperatures.
- Electronic optimization beyond the solubility limit.
- Mechanical properties (including CTE and H_V) and their variation with the composition and temperature.
    - Correlation between mechanical and transport properties (incl. the piezoresistive effect*).
- Minimization of degradation mechanisms.



π(piezoresistive coeff.)=($\Delta\rho/\rho$)·σ(applied stress)

* ***Piezoresistive effect*** – the change in the electrical resistivity when mechanical strain is applied