Thermoelectric materials and applications

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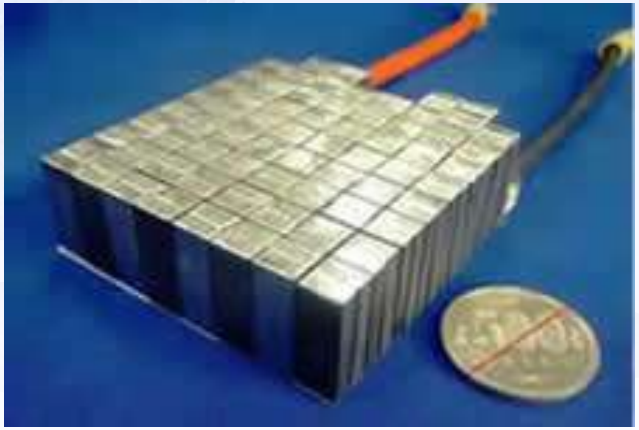

(1)

Overview

Principle

The Seebeck effect
Device configuration
Challenge

Materials

Overview
Examples
Roadmap

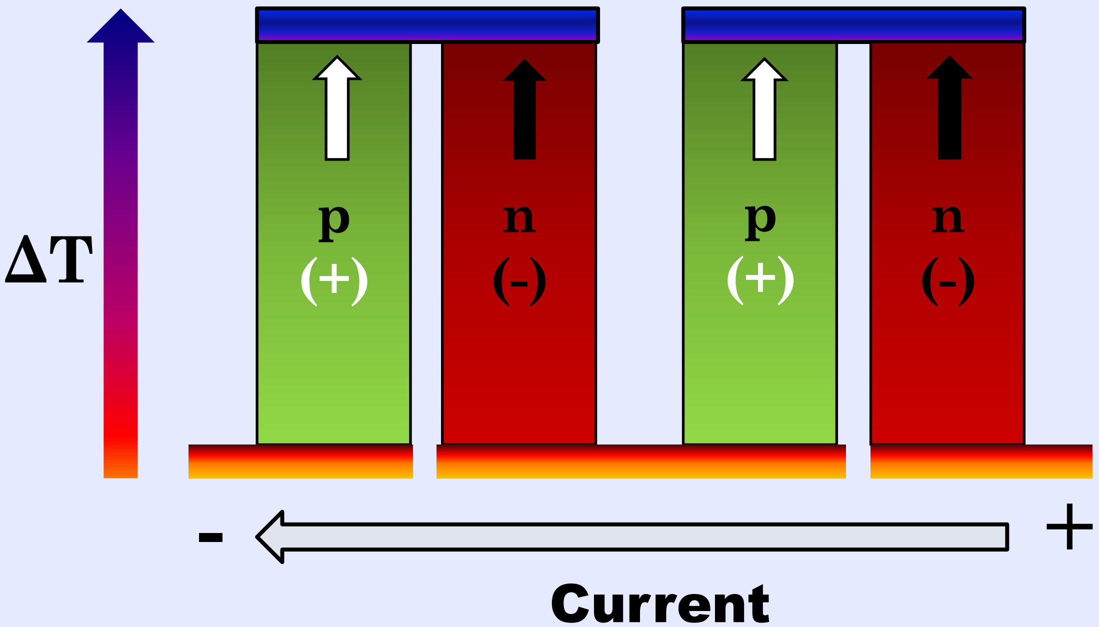
Applications

Steel furnace, desalination plant, biomass
Roadmap

Conclusion

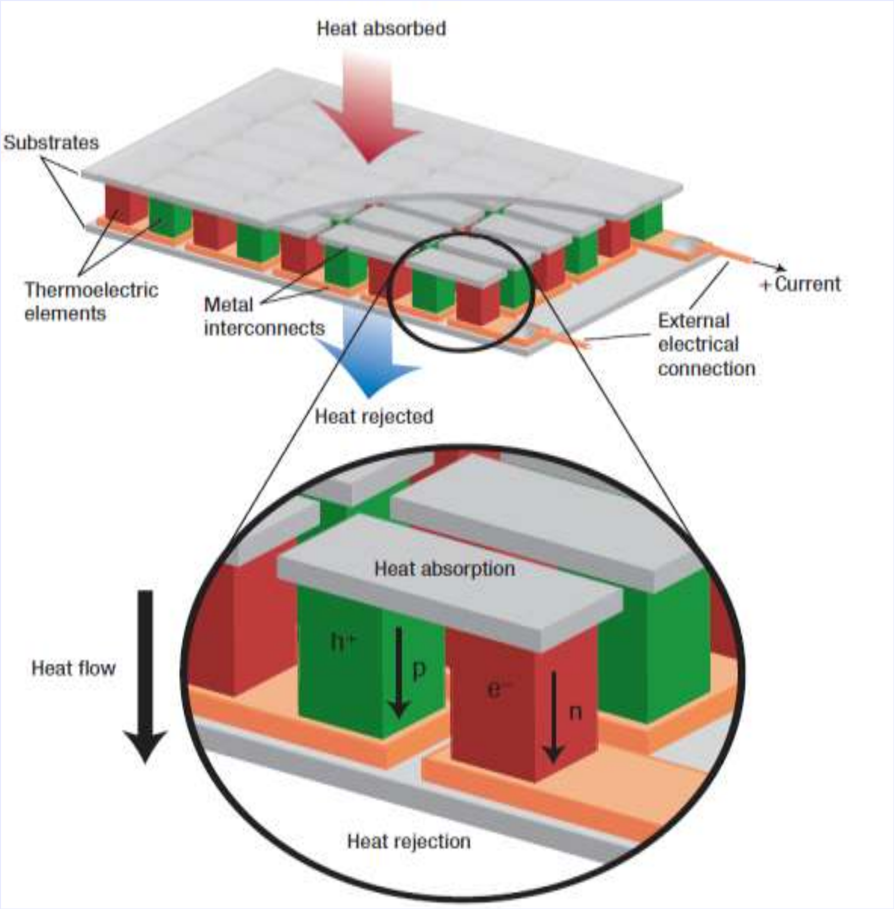
Principle

The Seebeck effect



Principle

Device configuration



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Principle

Challenge

κ = Thermal conductivity
(W m^{-1} K^{-1})

σ = Electrical conductivity
(Ω cm^{2})

ZT ≥ 2 needed for competitiveness

α = Seebeck coefficient
(V K^{-1})

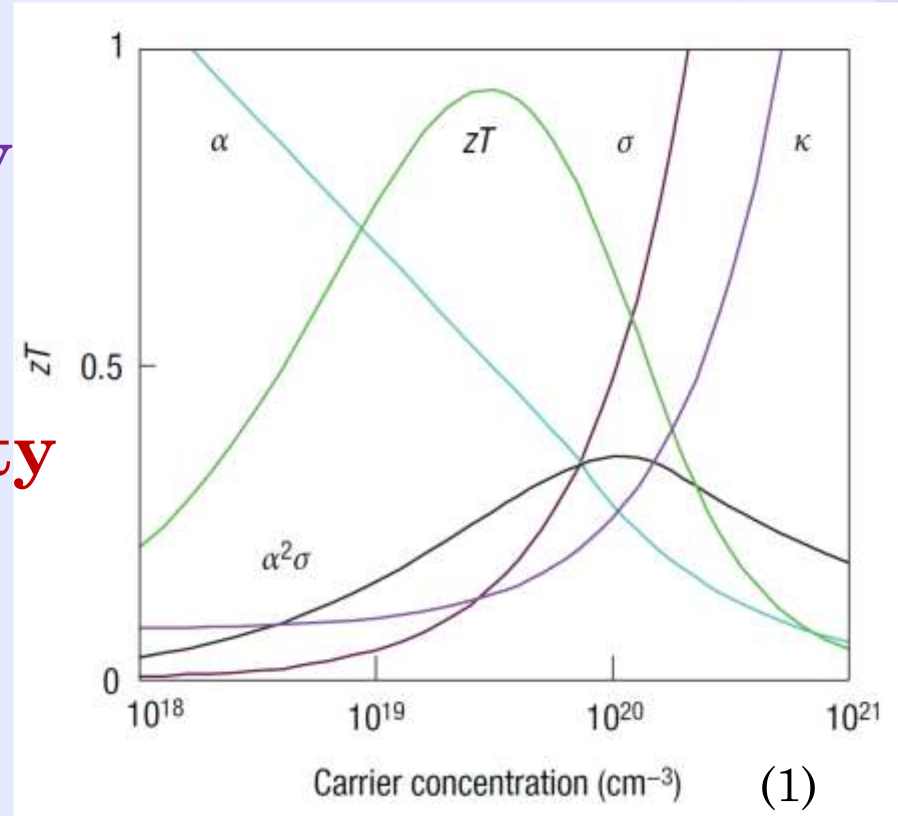

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Figure of merit: $ZT = \dfrac{\alpha^2 \sigma T}{\kappa}$

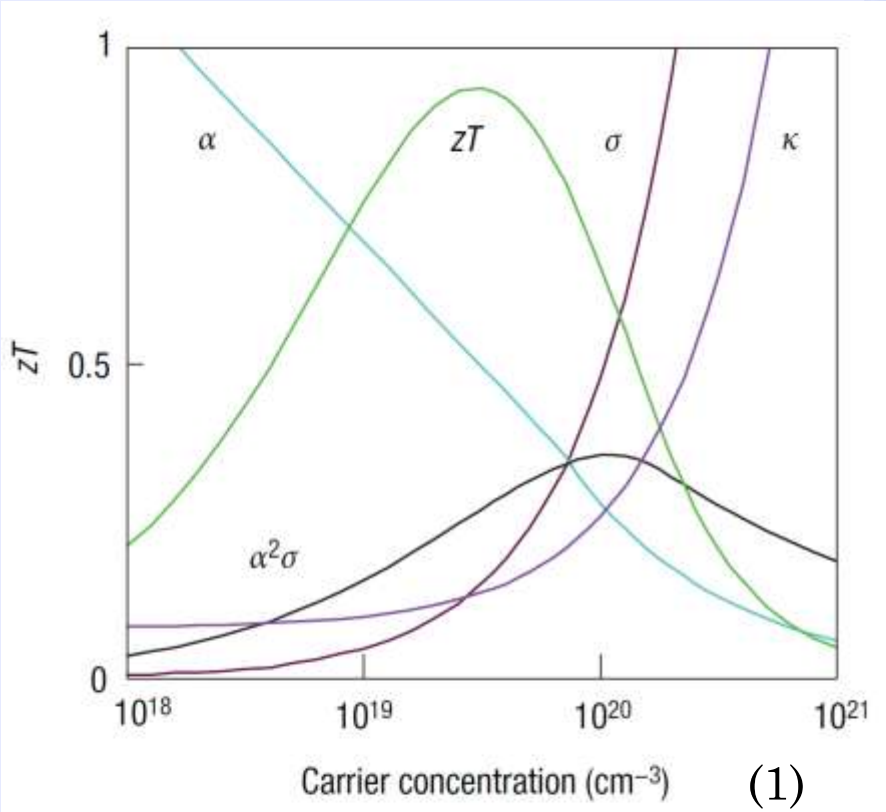
Principle

Challenge

Electrical conductivity ↑

Thermal conductivity ↑

ZT ↓ ☹



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Challenge:

Decouple Electrical and Thermal conductivity

→ Nanostructuring

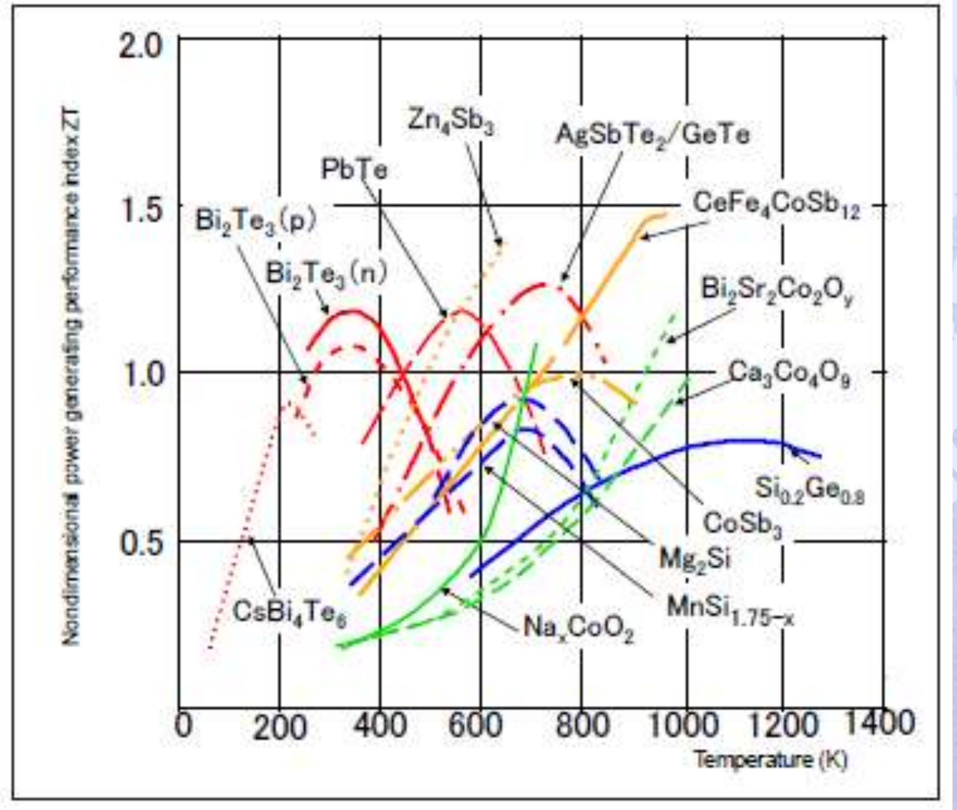
$$ZT = \frac{\alpha^2 \sigma T}{\kappa}$$

Materials
Overview

Each material has its own optimal working temperature

→Choosing the right material for the right application

Important factors:
- ◆Cost
- ◆Efficiency
- ◆Stability



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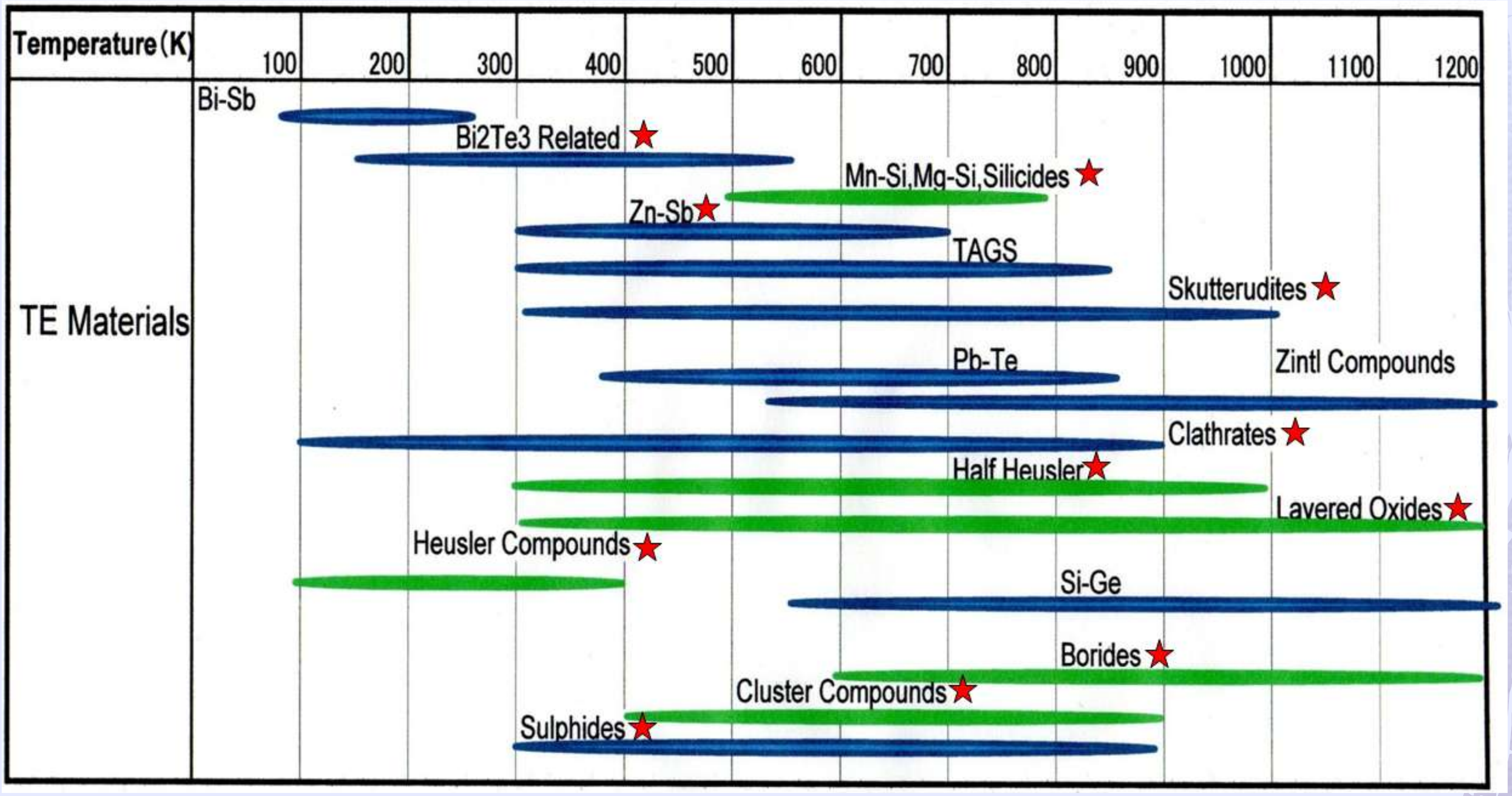
Materials
Overview

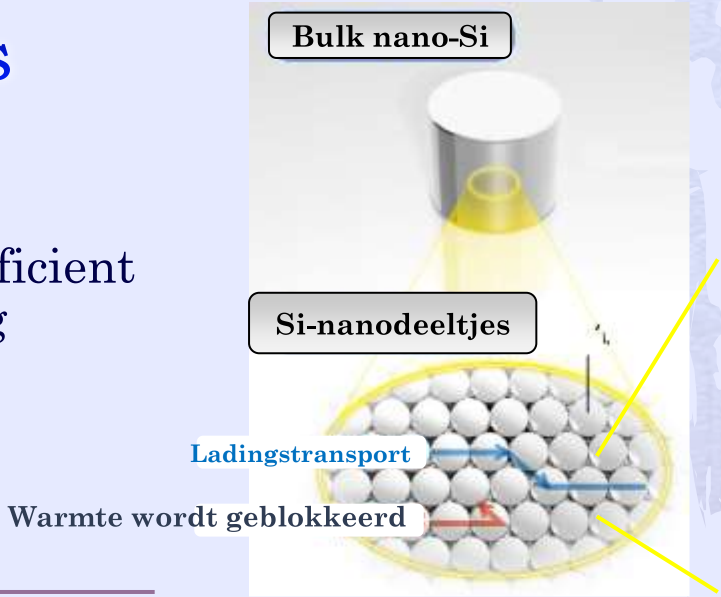


(★) Denotes research carried out in Japan
Source: Thermoelectric Society of Japan, Dr. T. Kajikawa)

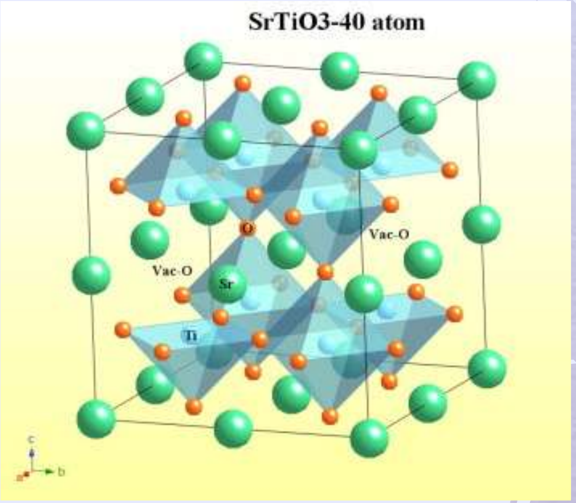
Materials

Examples

- **Bulk nano-silicon**
  - JST-CREST: “Development of High Efficient Silicon Thermoelectric Materials using Nanostructure Control” 2012 -2017 (¥150M)
    - Osaka University
    - AIST

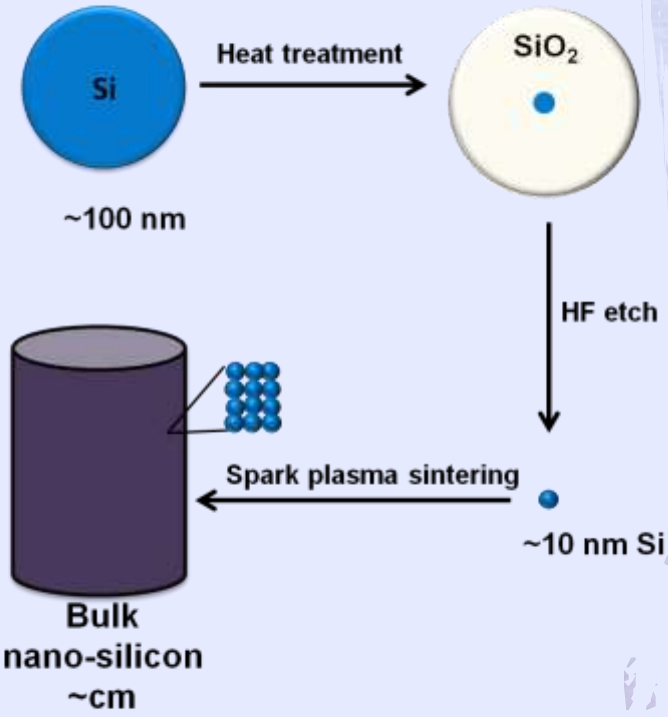


- **Oxide nanocubes**
  e.g. Strontium Titanate ($SrTiO_3$)
  - JST Project: “Development of High-Efficiency Thermoelectric Materials and Systems” FY 2007-2013 (¥227M)
    - Nagoya University
    - Hokkaido University
    - Tokyo University of Science, Yamaguchi
    - AIST



Materials
Bulk nano-silicon

1. Use ball-milling to get silicon (Si) particles
2. Oxidize Si particles
3. Etch away SiO_2
4. Use spark plasma sintering (SPS) to form bulk nano-silicon



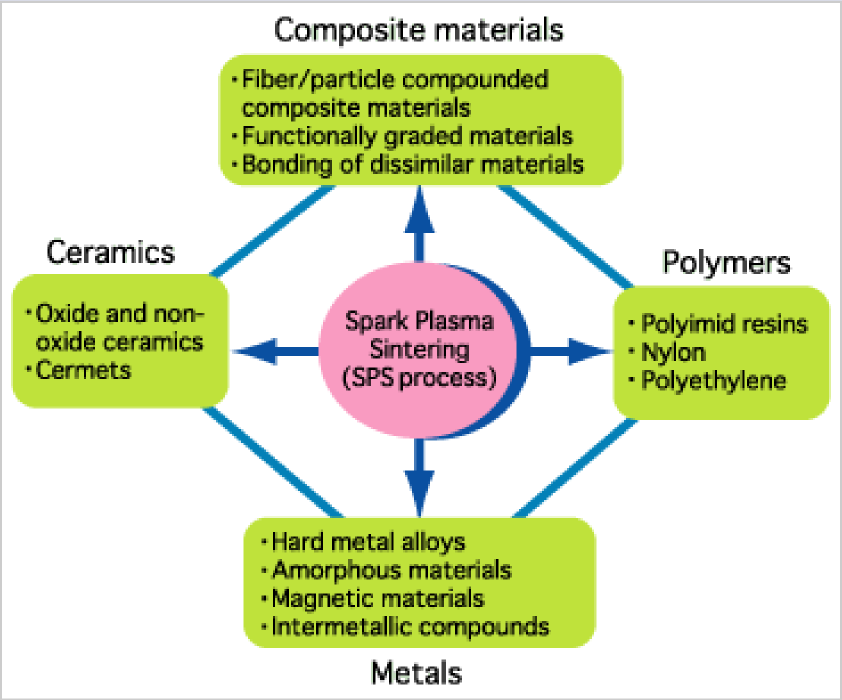
Goal: ZT >1 between RT and 300 °C

Materials
Spark plasma sintering

- Recently used to create the best (bulk) thermoelectric material in USA, *Nature* 2012/09
(ZT = 2.4)
  - However materials used (Lead Tellurium) are toxic
  - Japan wants to use life-friendly and abundant materials
- World leader in Spark Plasma Sintering (SPS) equipment is Fuji Electronic Industrial (3)

FDC

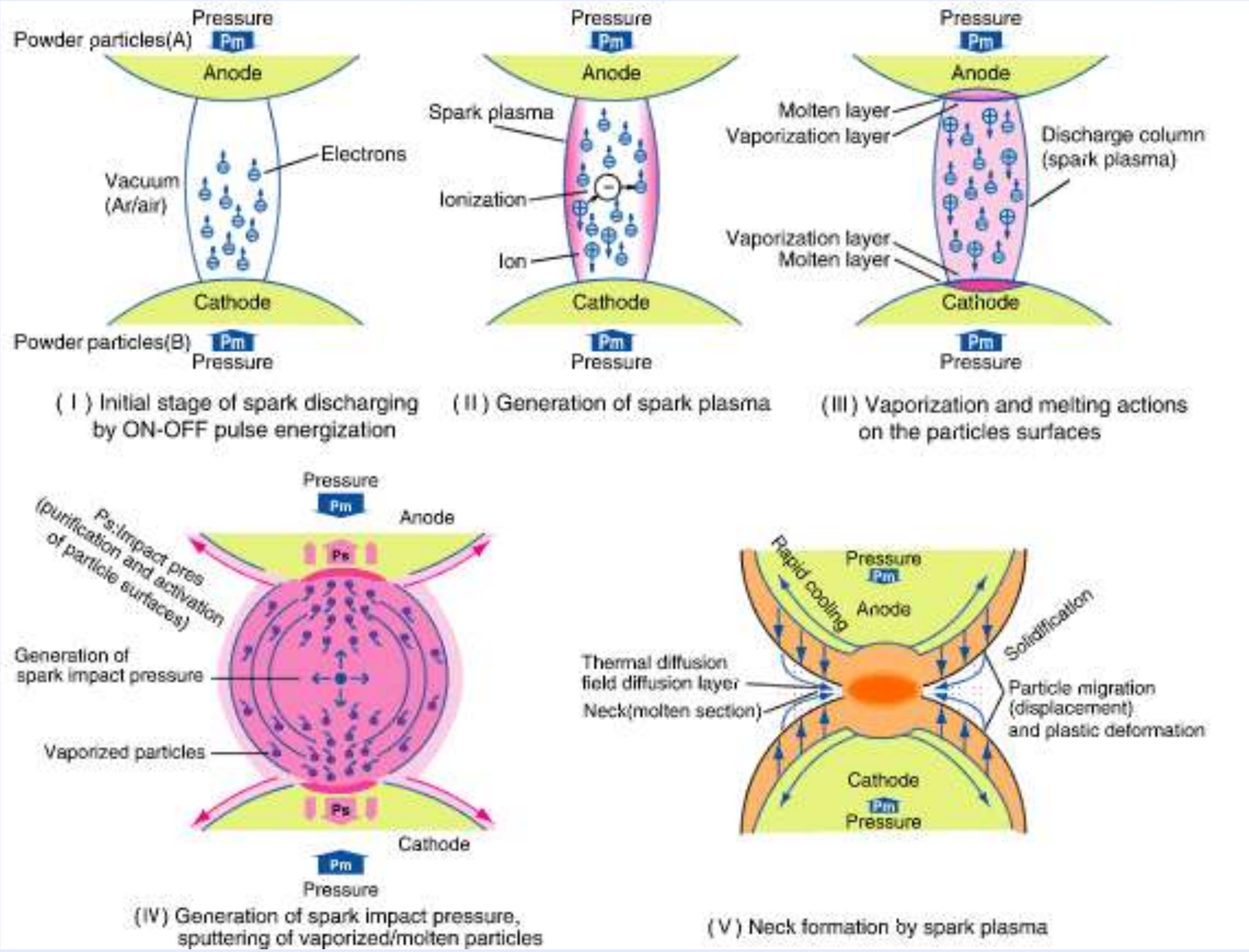
Materials
Spark plasma sintering



Classification		Materials for SPS processing
Metals		Fe,Cu,Al,Au,Ag,Ni, Cr,Mo,Sn,Ti,W,Be, Virtually any metal possible
Ceramics	Oxides	Al_2O_3,Mulite,ZrO_2,SiO_2 TiO_2,HfO_2,MgO
	Carbides	SiC,B_4C,TaC,TiC,WC,ZrC,VC
	Nitrides	Si_3N_4,TaN,TiN,AlN,ZrN,VN
	Borides	TiB_2,HfB_2,LaB_6,ZrB_2,VB_2
	Flourides	LiF,CaF_2,MgF_2
Cermets		Si_3N_4+Ni,Al_2O_3+Ni,ZrO_2+Ni Al_2O_3+TiC,SUS+ZrO_2,Al_2O_3+SUS SUS+WC/Co,BN+Fe,WC+Co+Fe
Intermetalic compounds		TiAl,$MoSi_2$,Si_3Zr_5,NiAl NbCo,NbAl,$LaBaCuO_4$,Sm_2Co_{17}
Other materials		Organic materials(polyimide,etc), Composite materials

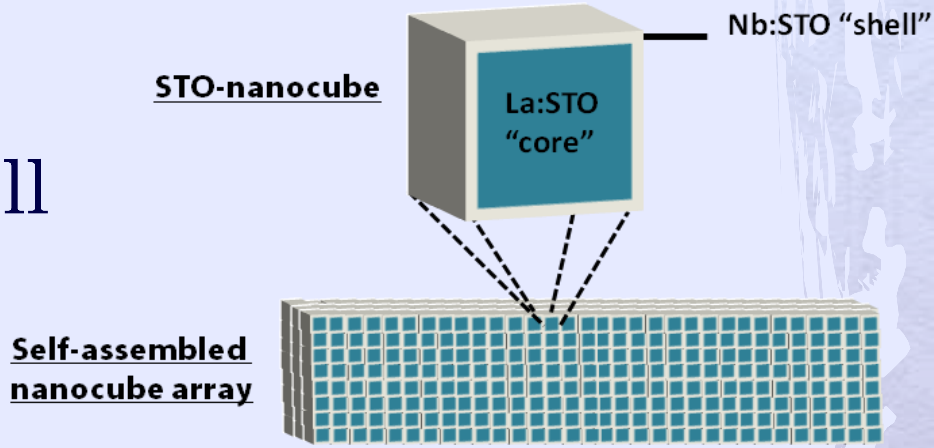
- Large variety of raw materials can be used
- Fast process
- New types of (nanostructured) materials

Materials
Spark plasma sintering



Materials
Oxide nanocubes

- Strontium Titanate (STO) nanocubes
  - Dope with a thin shell of Niobium
  - And a core of Lanthanum



→ 2D electron gas:
high electrical conductivity

→Many interfaces:
Low thermal conductivity

Materials
Government support

Date	Instance	Name project	Partners	Projectleader	Goal	Budget (Million Yen)	Note
2012 – 2017	JST	Development of High Efficient Silicon Thermoelectric Materials using Nanostructure Control	Osaka Univ., AIST	S.Yamanaka, Osaka Univ.	ZT ≥1 between RT and 600K for Nanostructured Si	150*	Bulk nano Si TE for 300°C, with a view for application in automobile heat recovery systems.
8.2011 – 2017	JST	Fabrication of Solar-Heat Thermoelectric Materials by Controlling Ordered Structures and Phase Interfaces	Tokyo Institute of Technology	Y. Kimura, Tokyo Tech.	Solar-heat TE power generation system	150*	1. Controlling Ordered Structures based on Half-Heusler system. 2. Controlling Phase Interfaces. For 650～1000 K using environmentally friendly TE materials.
1.2012 – 2015	NEDO	Development of Thermoelectric Generation Technology for Steel Plant Waste Heat Recovery	JFE Steel, KELK, Hokkaido Univ.	Hidetoshi Matsuno (JFE)	Create a 10 kW test system. Optimize power efficiency without impairing steel production	140	Press release KELK: http://www.komatsu.com/CompanyInfo/press/2012041912512625132.html
6.2009 – 3.2012	NEDO	Research and Development of High-performance Nano-structured Thermoelectric Materials Using Caged Compounds	Yamaguchi Univ., Hiroshima Univ., AIST, KELK, DENSO	T. Takabatake, Hiroshima Univ.	1. ZT=1.3 at delta T=300 ºC 2. Development of High-performance TEG Systems for Practical Use	810	Nano-scale caged material $Ba_8Ga_{16}Sn_{30}$ (BGS and BGCS)
10.2008 – 4.2014	JST	Development of High-Efficiency Thermoelectric Materials and Systems	Nagoya Univ., AIST, Hokkaido Univ., Tokyo Univ. of Science at Yamaguchi	K. Koumoto, Nagoya Univ.	ZT>1.5, η～10%. Non-toxic, Non-rare, Cheap, and Usable in Air for wide temperature range	227	-
4.2009 – 3.2012	MEXT	Development of Novel Thermoelectric Modules by Ink-jet Technique	JAIST, KELK	Mikio Koyano (JAIST)	Printable TEG	26	-
4.2011 – 3.2016	MEXT	Development for High Temperature Thermoelectric Materials to recover unused waste heat sources	NIMS	Yoshikazu Shinohara	-	23	Complex structured materials such as $RB_{17}CN$ and $RB_{22}C_2N$ and Higher Borides