MESA+
INSTITUTE FOR NANOTECHNOLOGY

UNIVERSITY OF TWENTE.

Enhanced Thermoelectric Energy Conversion by Advanced Thin Film Technology

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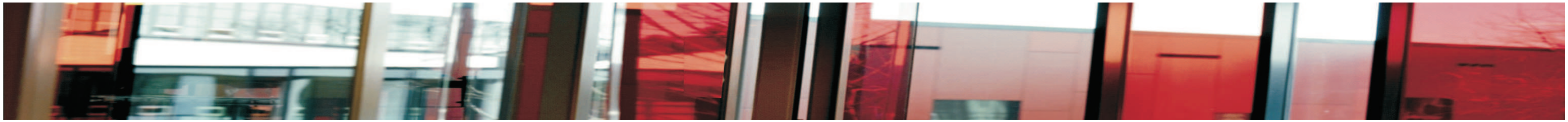
MESA+ Institute for Nanotechnology

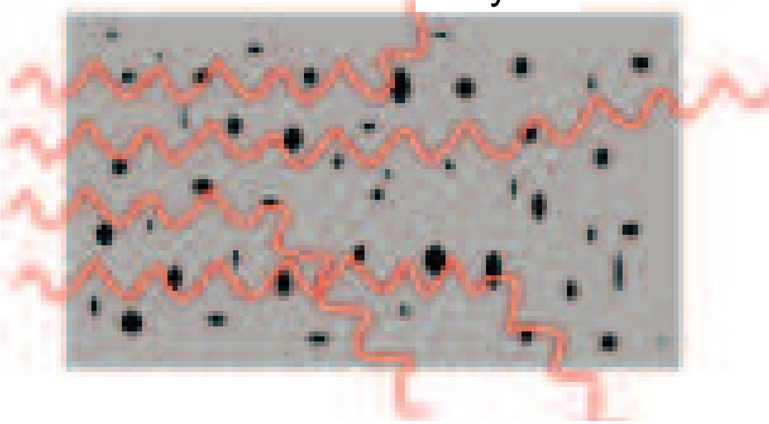
University of Twente, The Netherlands



Controlled scattering at thin film interfaces

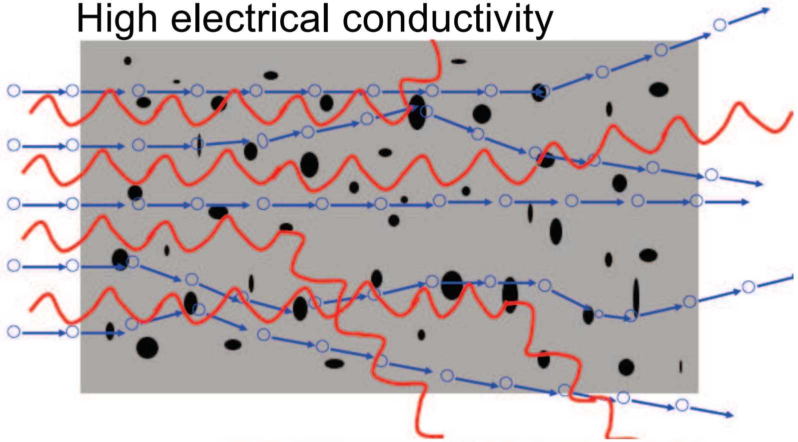
Phonons scatter at the interfaces

Low thermal conductivity

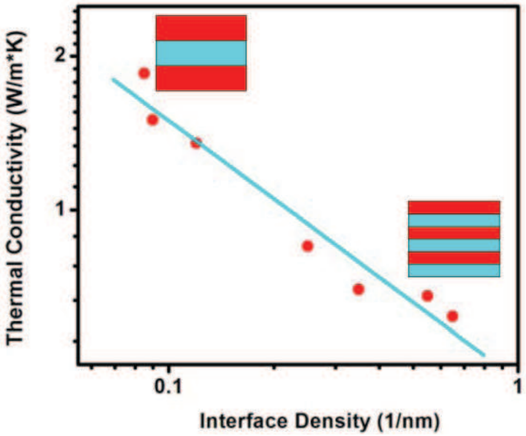


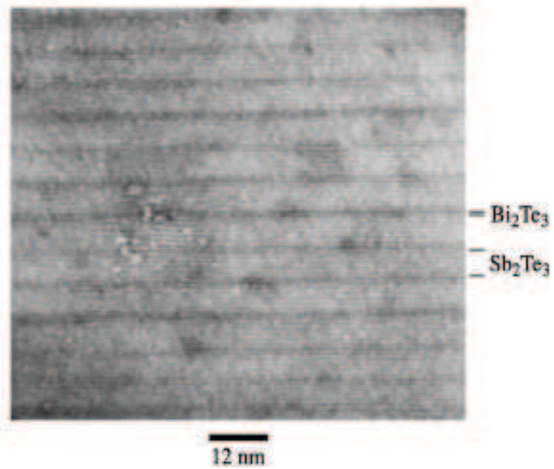
Electrons hardly see the interfaces

High electrical conductivity



Reduced thermal conductivity





Venkatasubramanian, *Nature* **413**, 597 (2001).

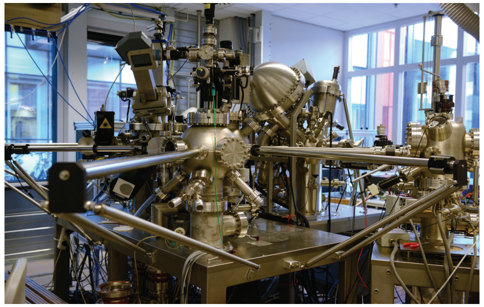
University of Twente: MESA+ Nanolab

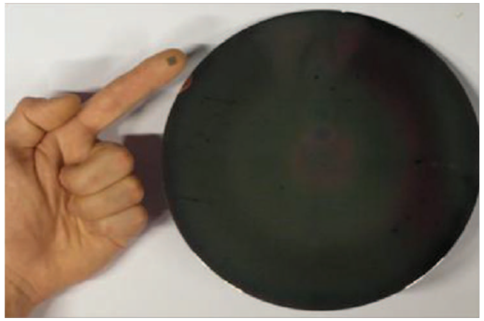
Unique expertise : Epitaxial thin film technology

Aim:
Novel properties and functionalities by atomic level engineering of complex functional oxide materials

Pulsed laser deposition
(shared research facility at Nanolab)
9 PLD systems with variable:

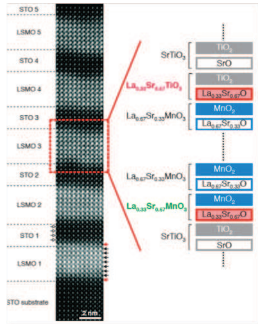
- in-situ characterization tools (RHEED, XPS, XPD, UPS, STM, AFM)
- dimensions (0.5 - 20 cm diameter = 8 inch industrial Si wafers)





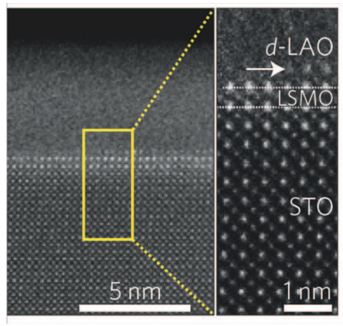
Examples of interface engineering by Huijben *et al.*:

Enhanced local magnetization



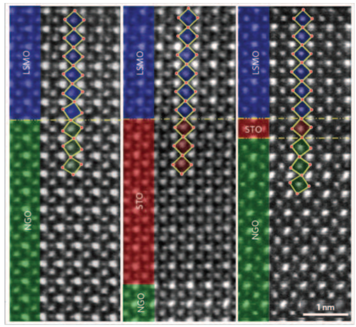
Adv. Mater. Interf. 2, 1400416 (2015)

Extreme mobility enhancement



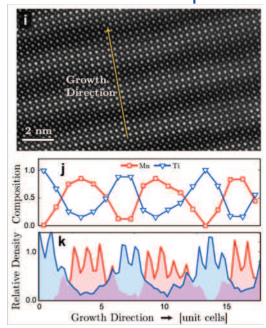
Nature Materials 14, 801 (2015)

Controlled octahedral rotations

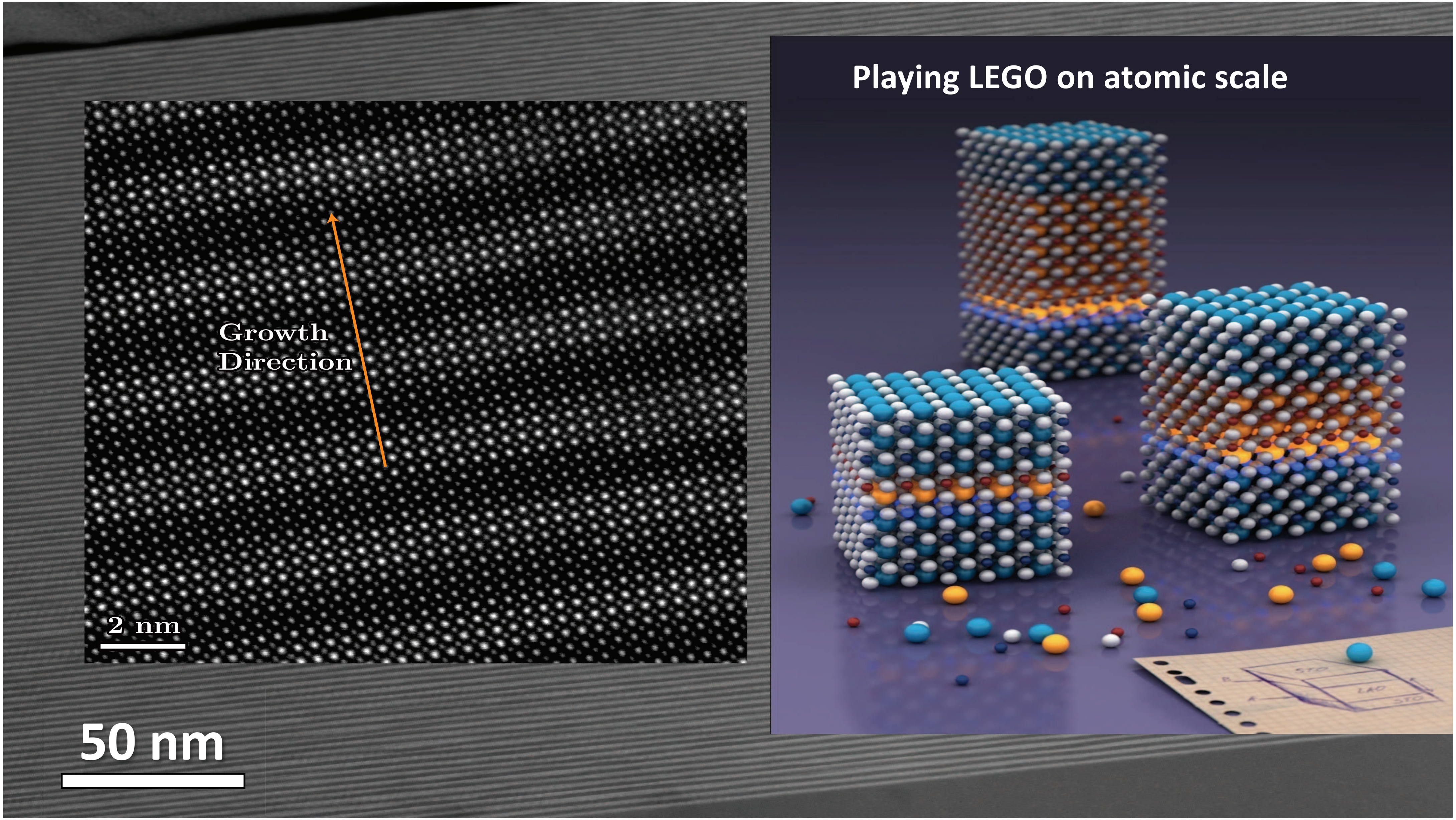


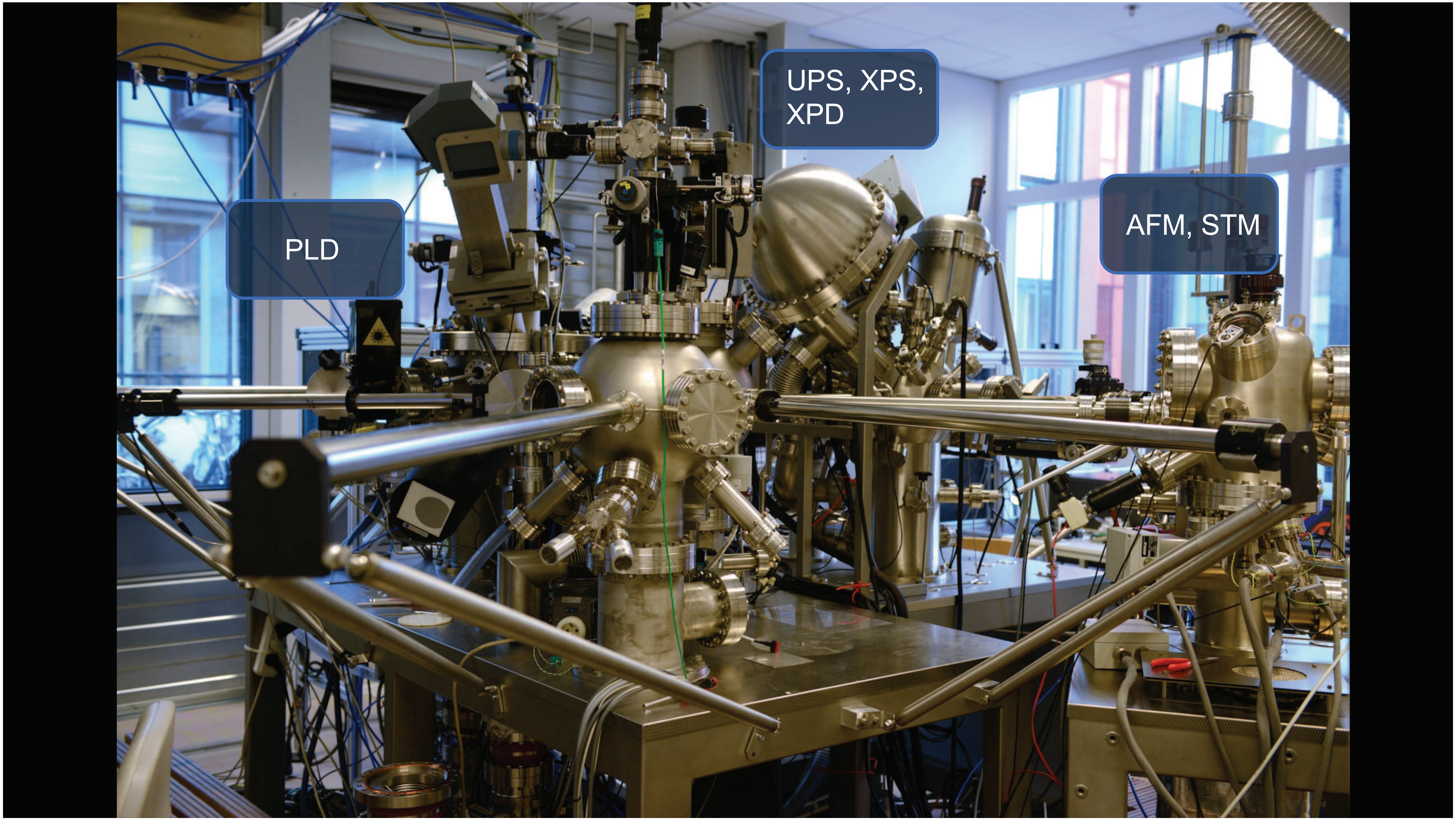
Nature Materials 15, 425 (2016)

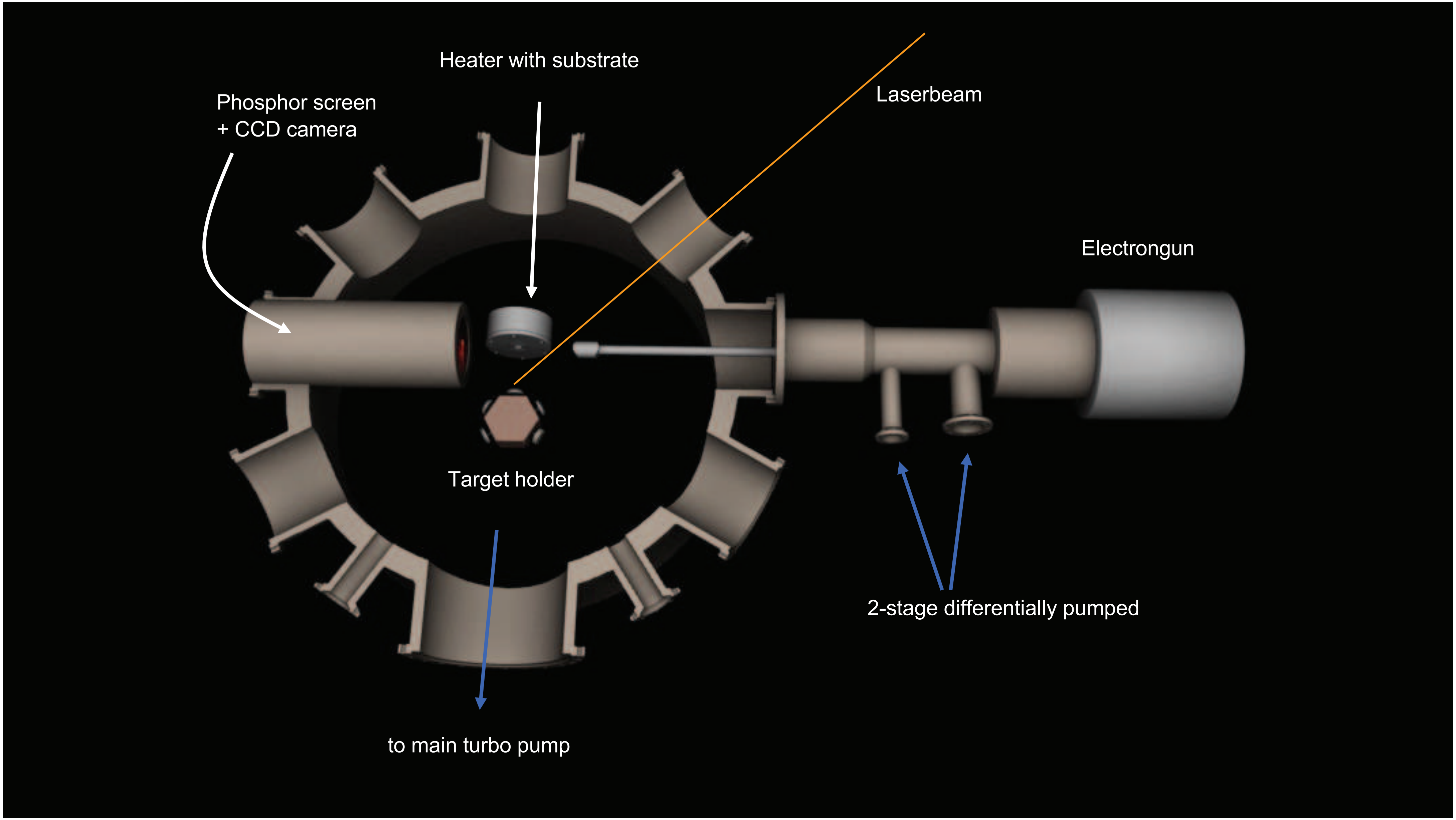
Atomic-scale composition



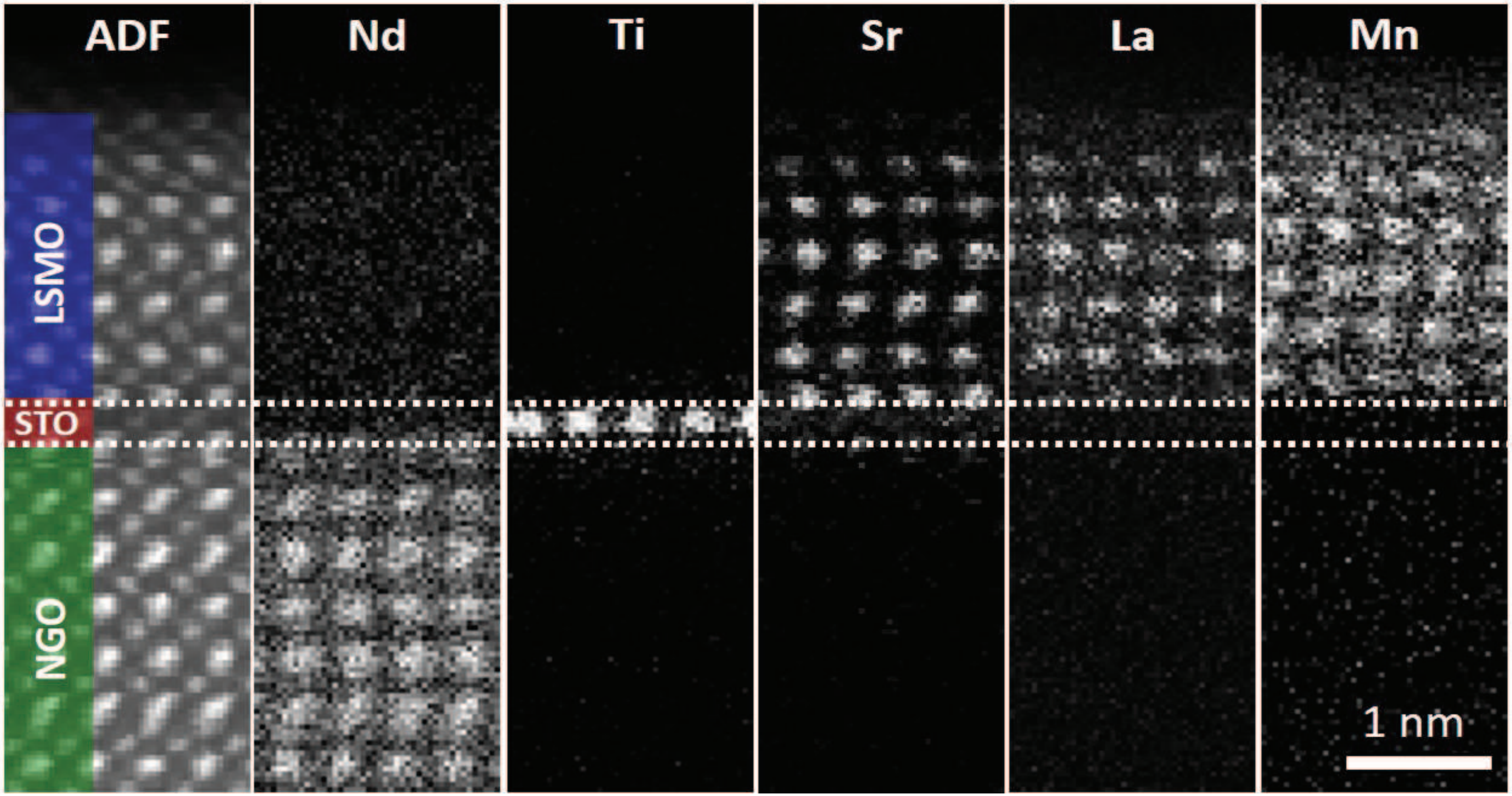
Appl. Phys. Lett. 110, 063102 (2017)


Growth
Direction
2 nm
Playing LEGO on atomic scale
50 nm


UPS, XPS,
XPD
PLD
AFM, STM

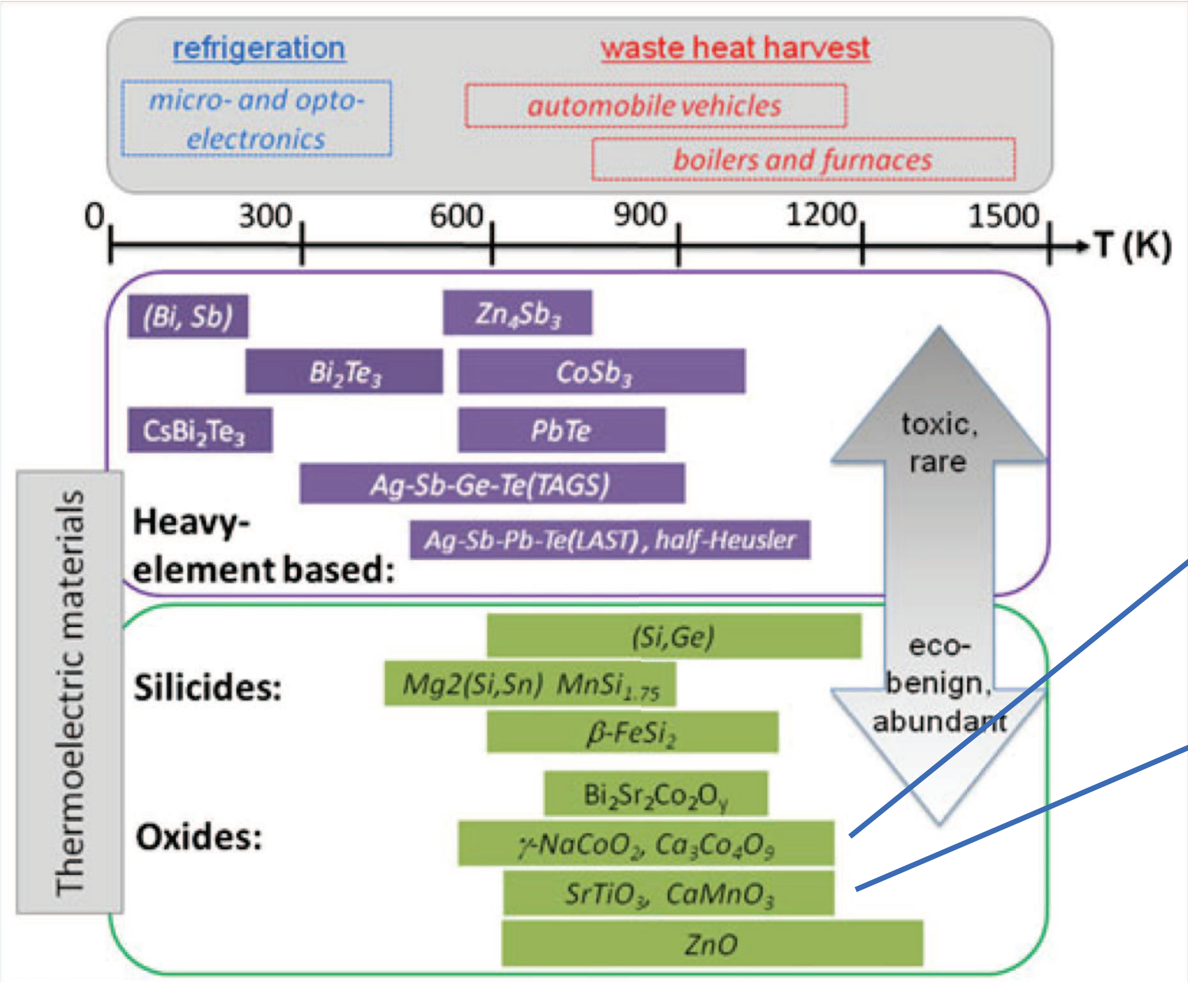

Heater with substrate
Phosphor screen
+ CCD camera
Laserbeam
Electrongun
Target holder
2-stage differentially pumped
to main turbo pump

Atomically controlled thin film growth



Nature Materials 15, 425 (2016)

Thermoelectric materials



J. He *et al.*, *J. Mater. Res.* **26**, 1762 (2011).

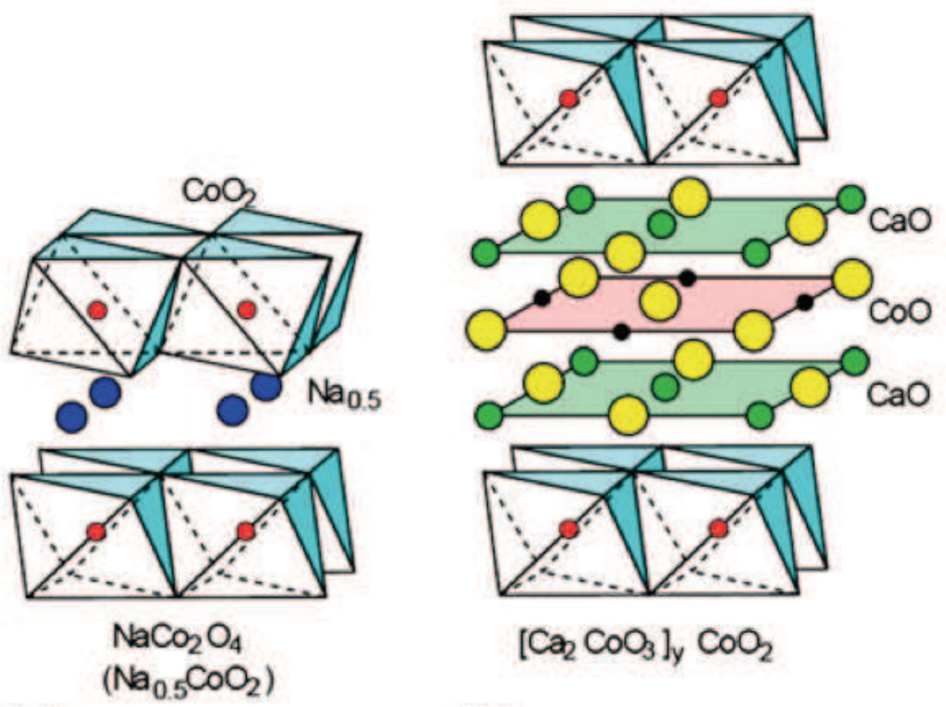
$NaCoO_2$ and $Ca_3Co_4O_9$

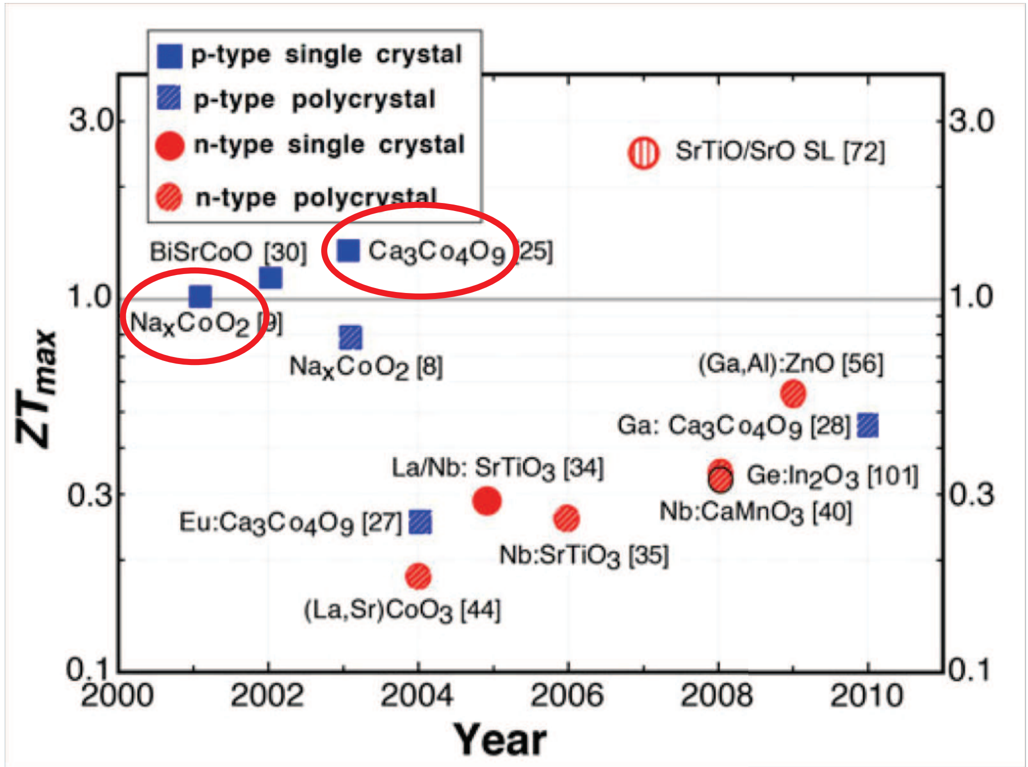
UNIVERSITY OF TWENTE.

$Sr_{1-x}La_xTiO_{3-\delta}$

Appl. Phys. Lett. **92**, 092118 (2008)
Appl. Phys. Lett. **92**, 191911 (2008)
Appl. Phys. Lett. **92**, 202113 (2008)
Chem. Mater. **22**, 3983–3987 (2010)
Appl. Phys. Lett. **98**, 221904 (2011)
Phys. Rev. B **83**, 035101 (2011)

Layered cobatites

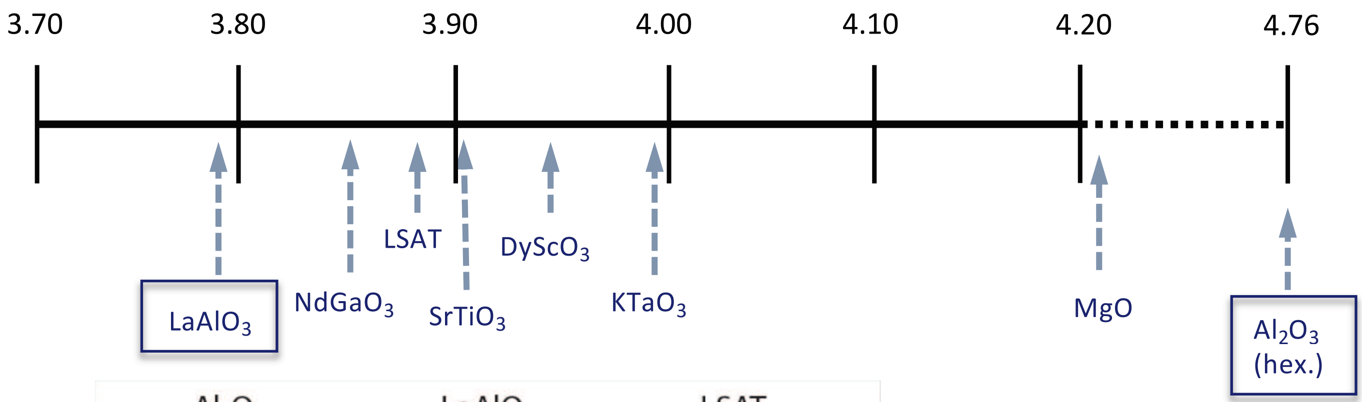


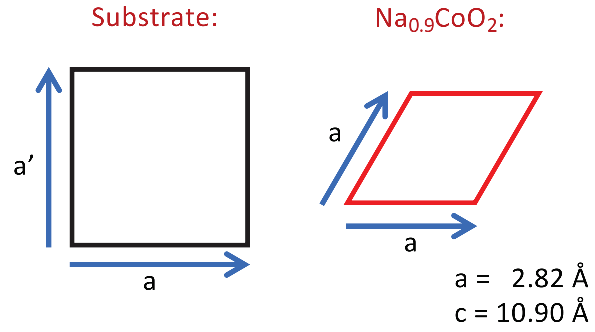


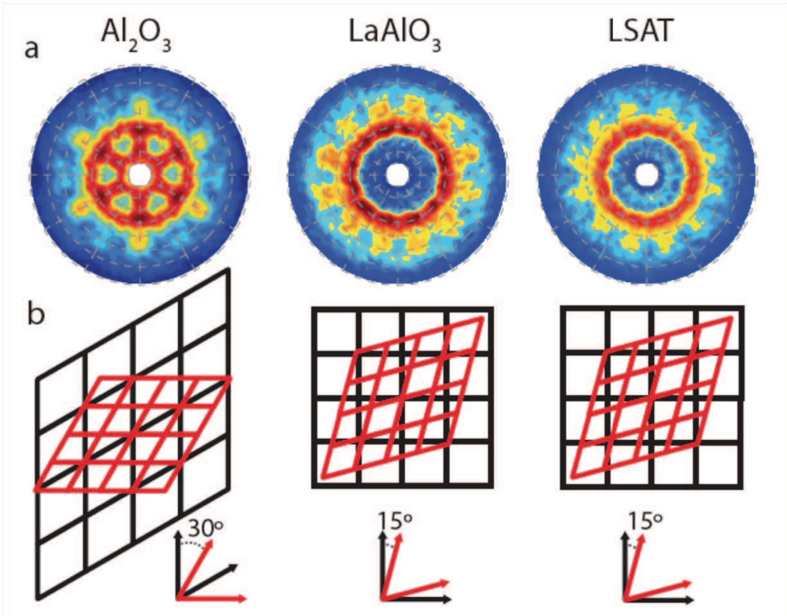
J. He *et al.*, *J. Mater. Res.* **26**, 1762 (2011).

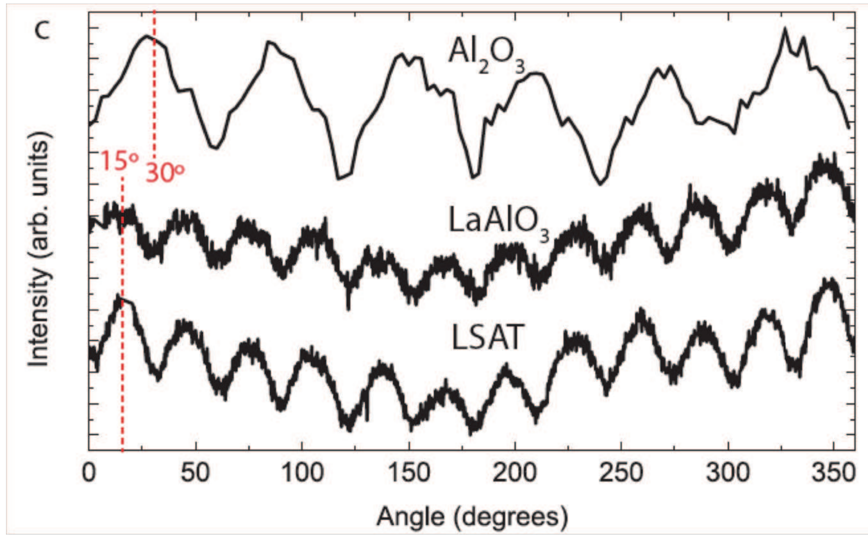
Epitaxial engineering

Advanced Energy Materials ***4****, 1301927 (2014)*





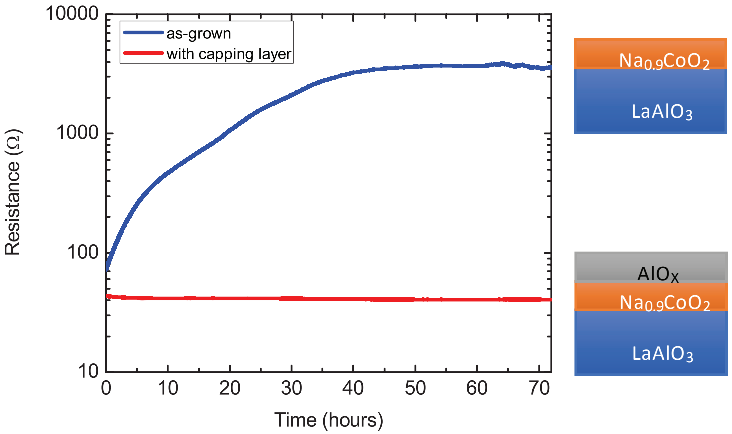




Thermoelectric Na_xCoO_2 thin films

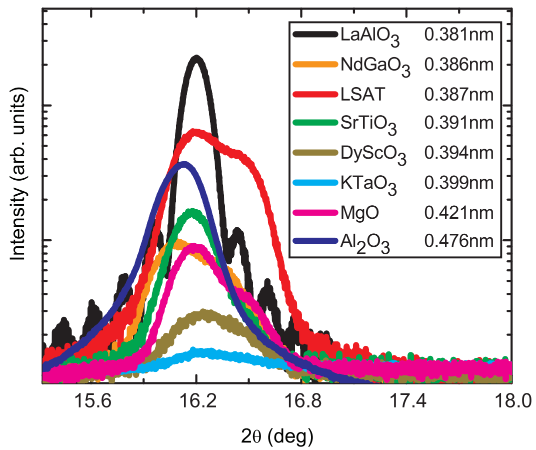
Enhanced chemical stability

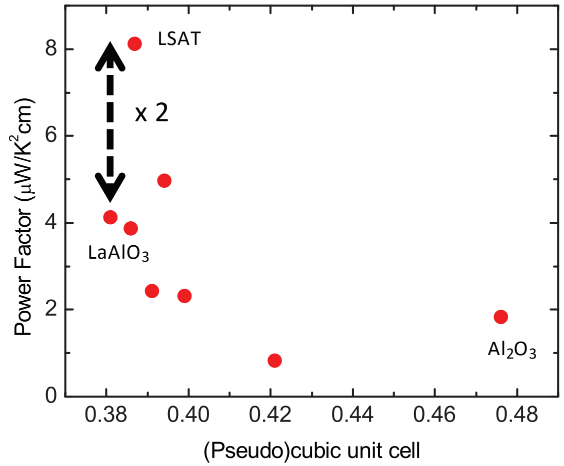
RSC Advances **2**, 6023-6027 (2012)



Enhanced thermoelectric power factor

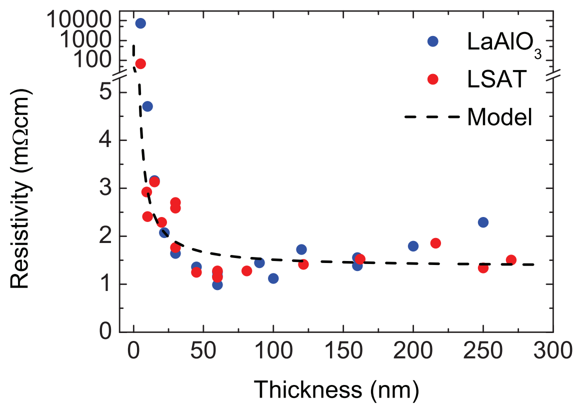
Advanced Energy Materials ***4**, 1301927 (2014)*

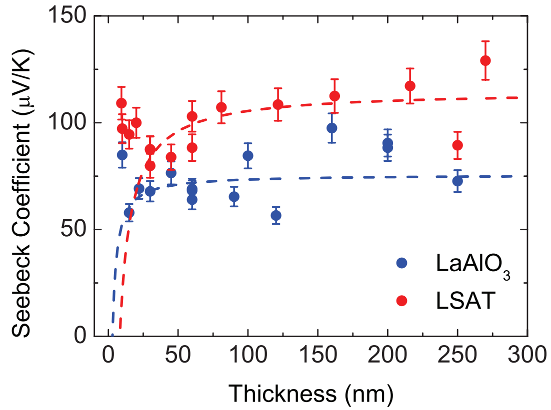




Thickness dependent size effects

Appl. Phys. Lett. **105**, 193902 (2014)



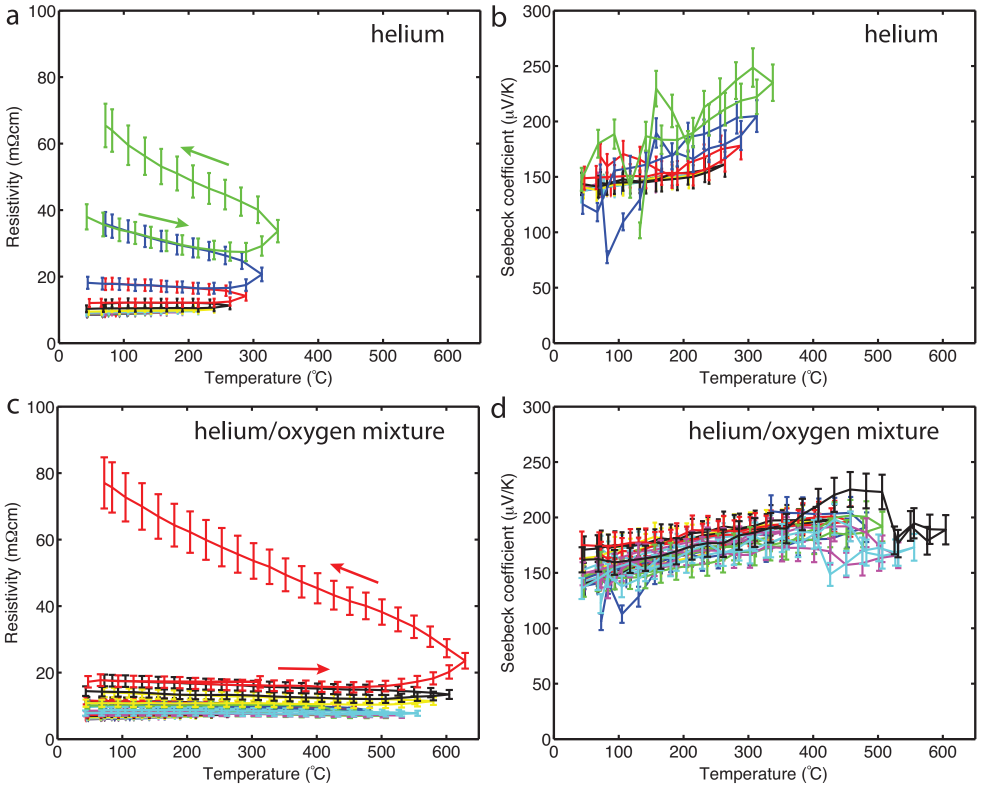


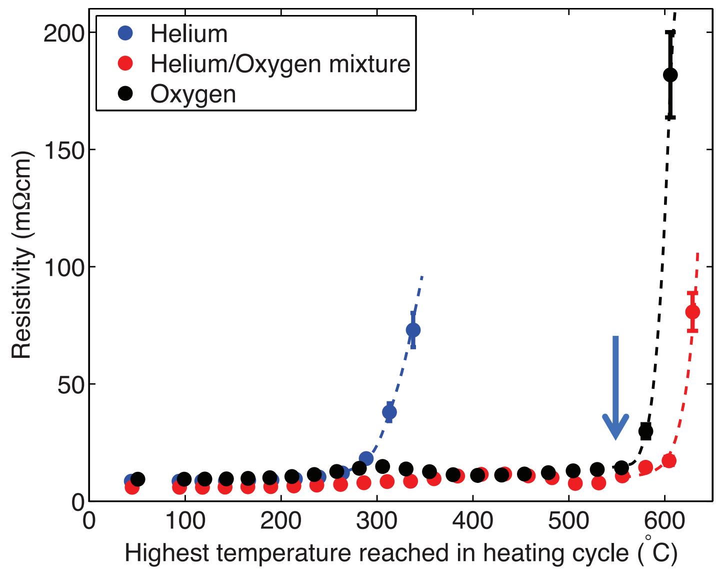
Tellier's and Pichard's models

Thermoelectric $Ca_3Co_4O_9$ thin films

High temperature stability

Appl. Phys. Lett. **106**, 143903 (2015)



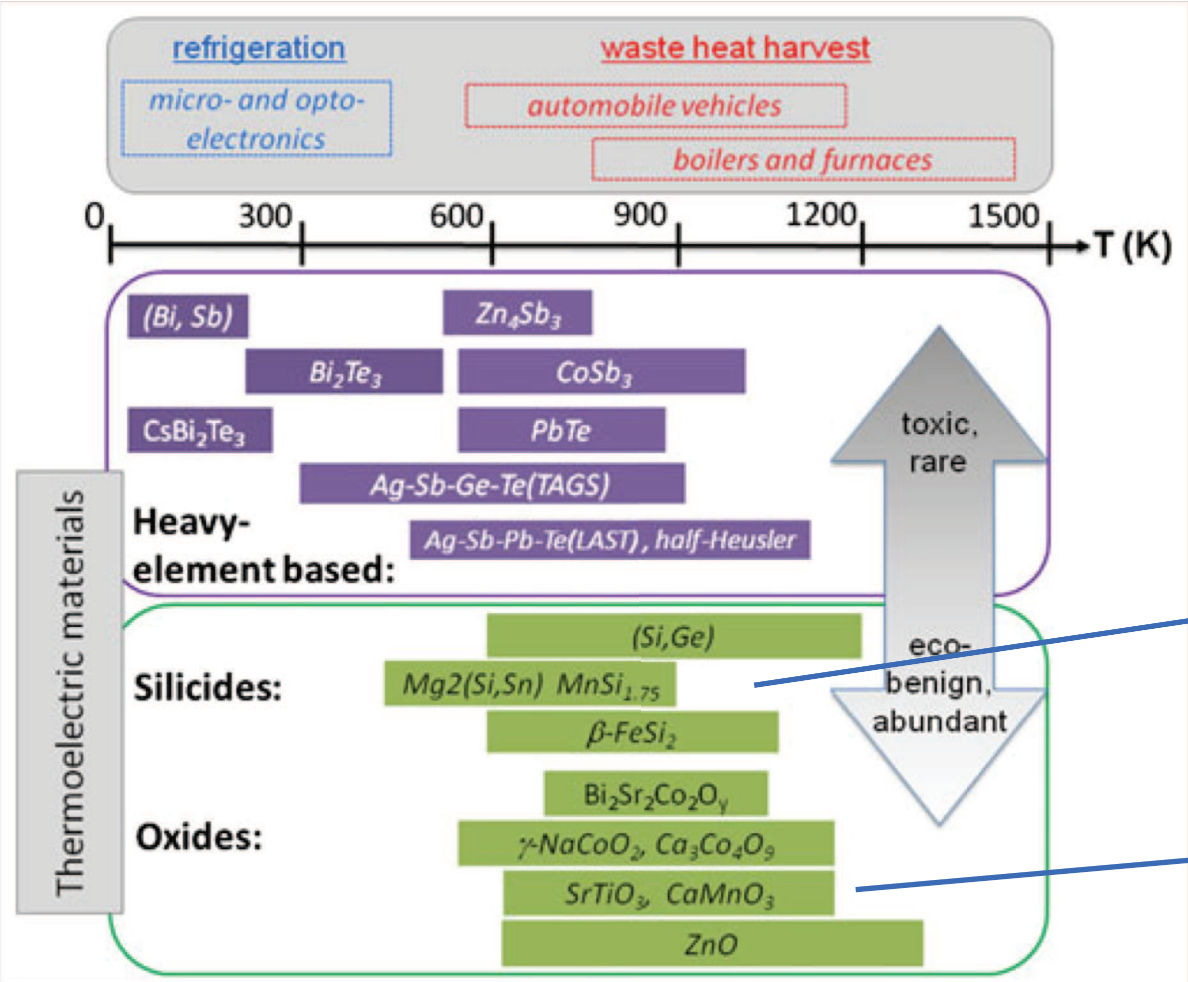


Bulk CCO:
3.0×10^{-4} $Wm^{-1}K^{-2}$

At 550 °C :

7.1 mΩ•cm
192 μV/K
5.2×10^{-4} $Wm^{-1}K^{-2}$

Thermoelectric materials



TATA STEEL

RGS development B.V.

Silicon Technology

$MnSi_{1.7}$

$NaCoO_2$ and $Ca_3Co_4O_9$

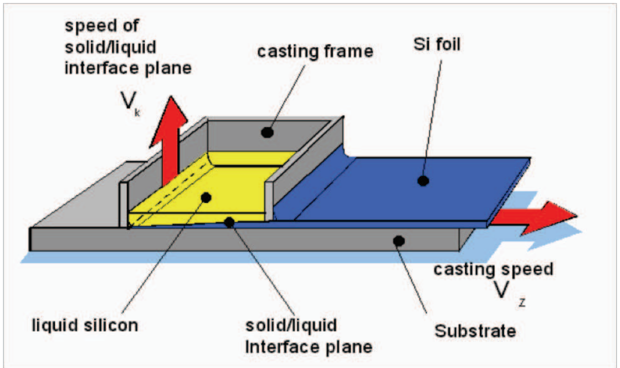
$Sr_{1-x}La_xTiO_3$

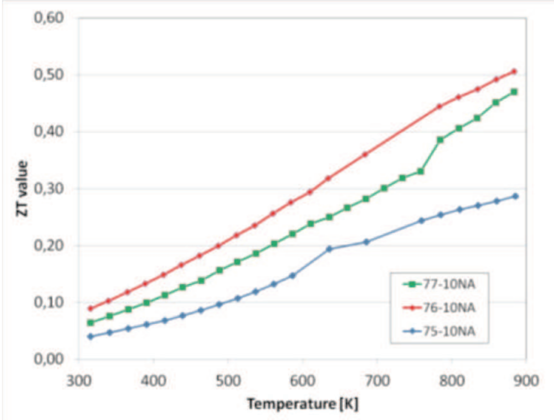
J. He *et al.*, *J. Mater. Res.* **26**, 1762 (2011).

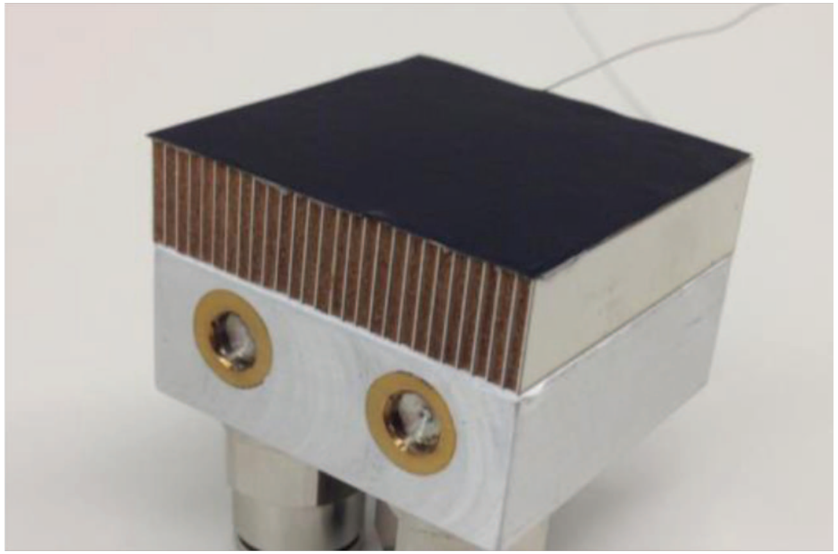
Higher manganese silicides

Manufacturing of thermoelectric modules

Materials Today: Proceedings **2**, 538 – 547 (2015)





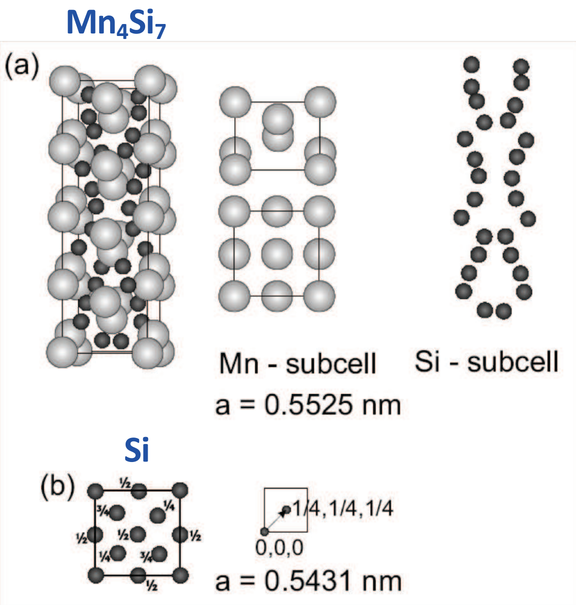


ribbon-growth-on-substrate (RGS) technology

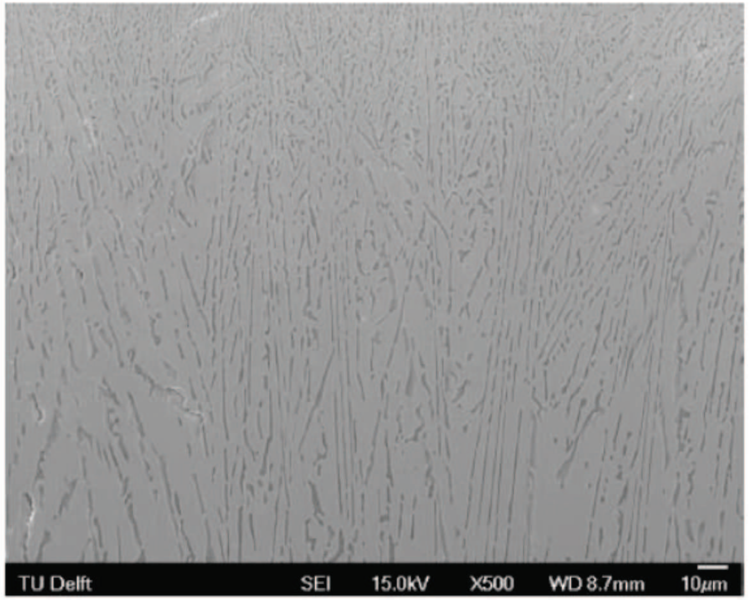
Higher manganese silicides

Enhanced phonon scattering by phase structuring of Si in HMS phase.

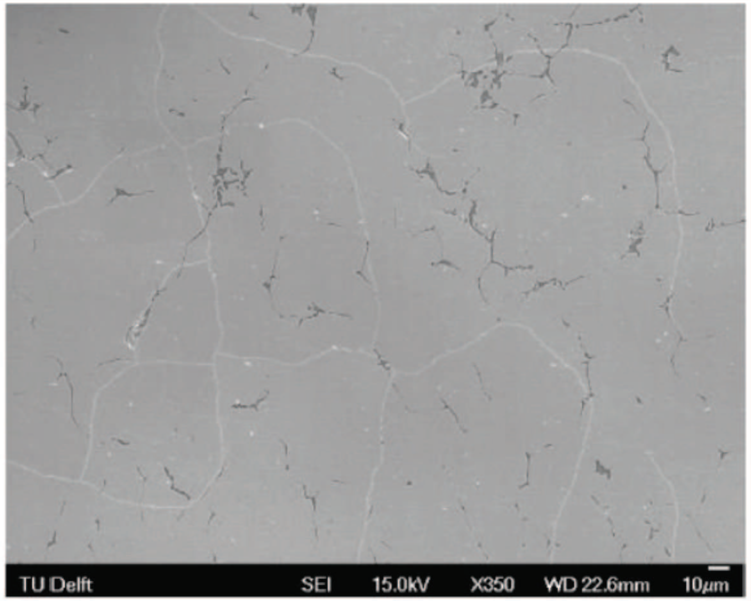
Materials Today: Proceedings **2**, 538 – 547 (2015)



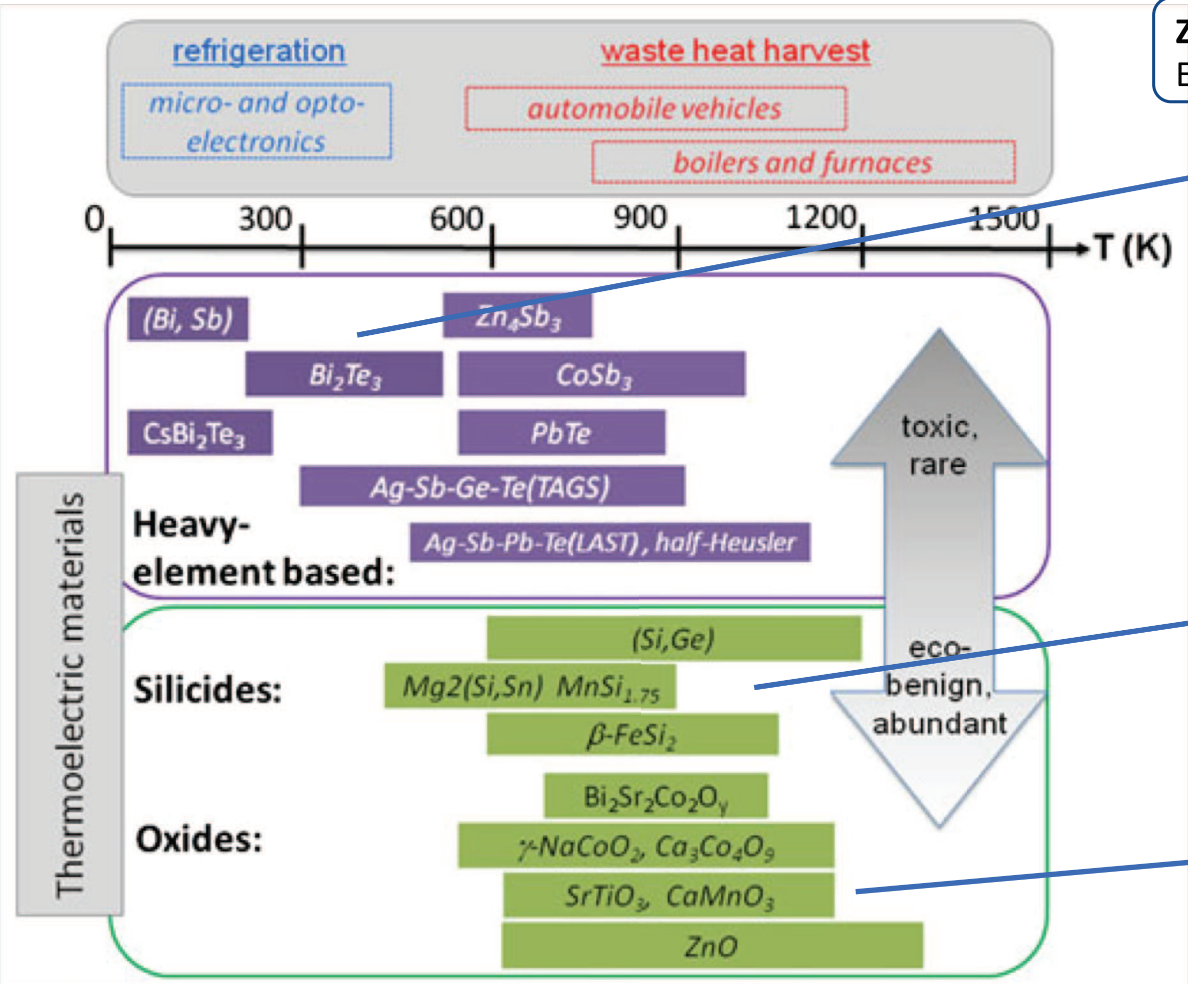
Sideview



Topview



Thermoelectric materials



J. He *et al.*, *J. Mater. Res.* **26**, 1762 (2011).

ZERO :
Energy Autonomous Systems for Internet of Things

NWO

SnSe

$MnSi_{1.7}$

$NaCoO_2$ and $Ca_3Co_4O_9$

$Sr_{1-x}La_xTiO_3$

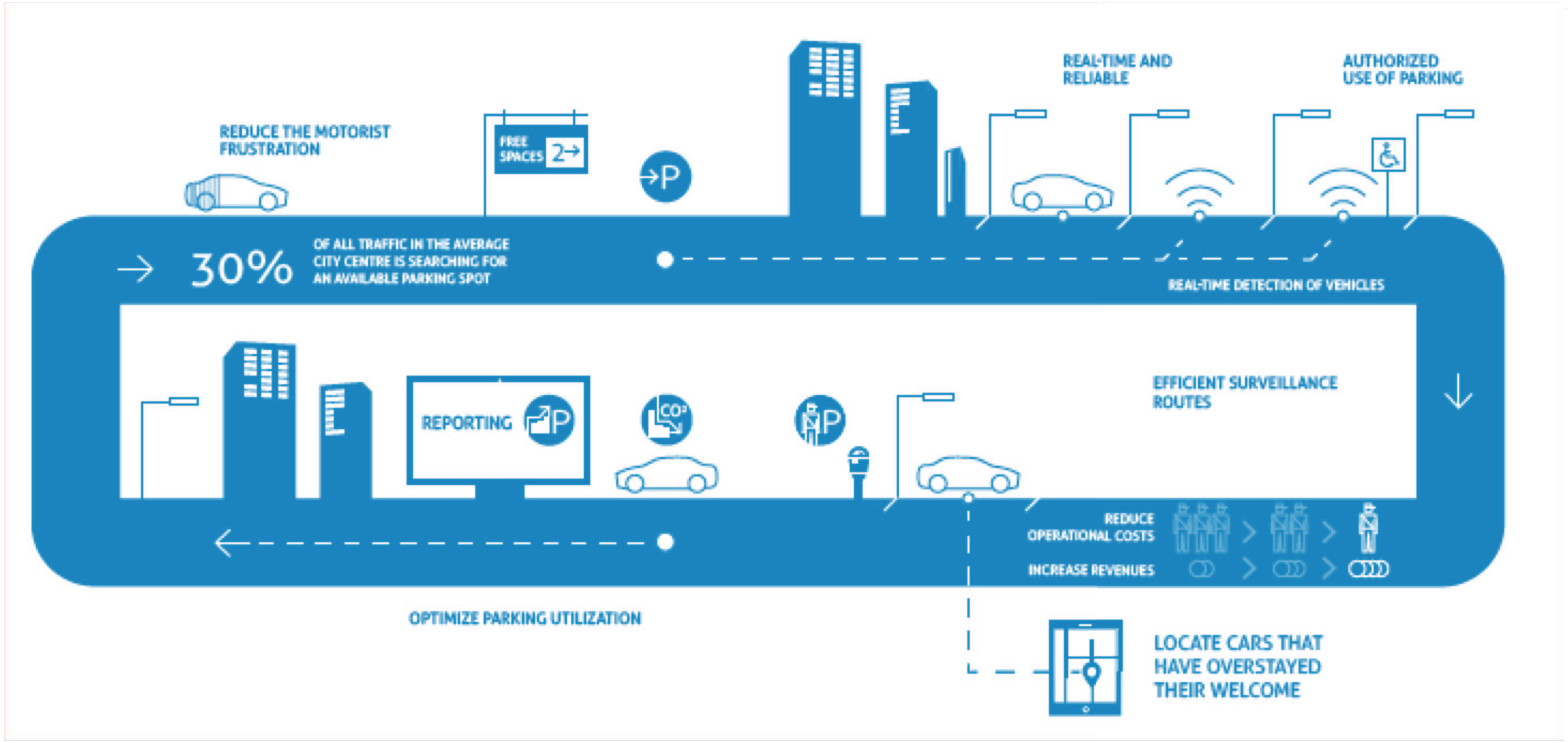
Autonomous Parking Sensor Networks

nedap | mobility solutions

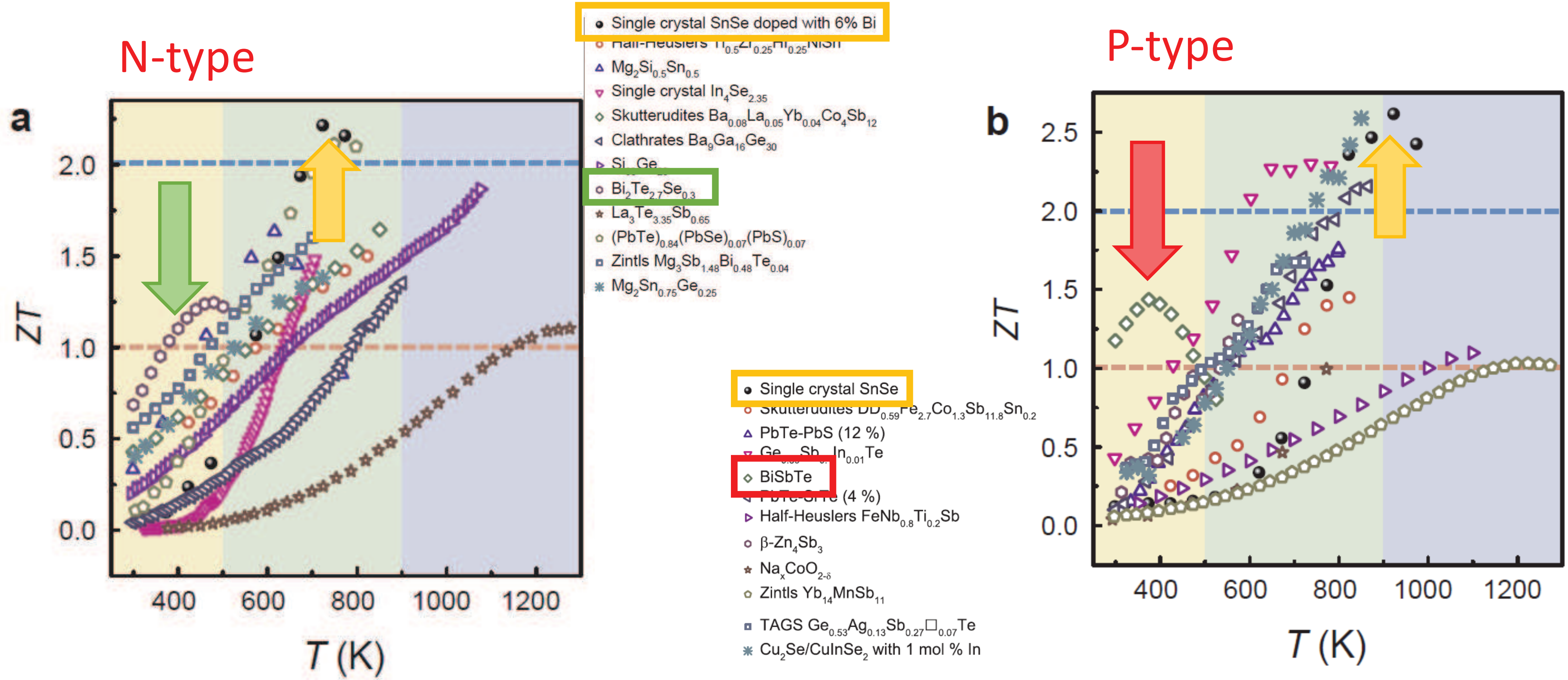
Autonomous Parking Sensor Networks

Based on Internet-of-Things (IoT) and 5G-network

nedap | mobility solutions



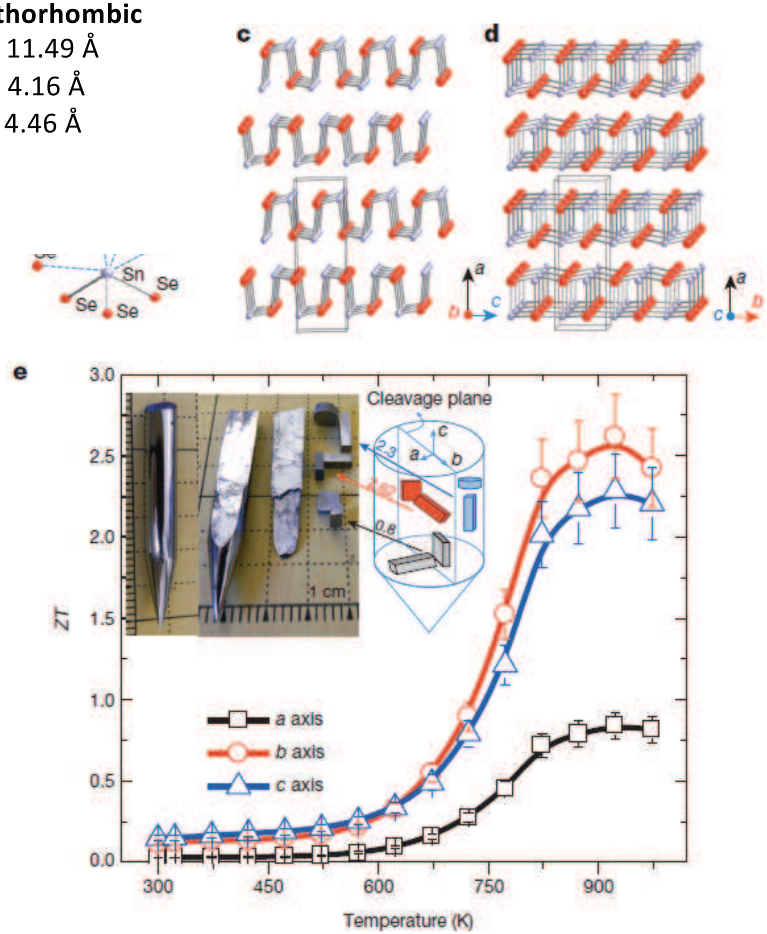
Promising thermoelectric materials



Chen, Z.-G., et al. (2018). Progress in Materials Science **97**: 283-346.

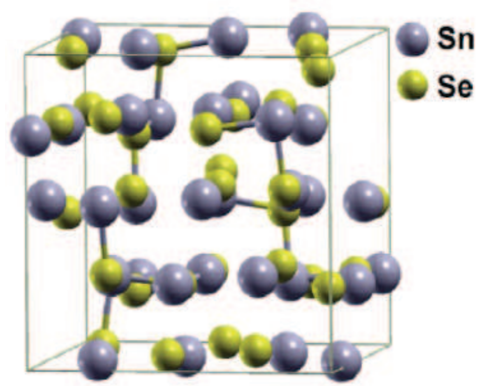
Tin Selenide (SnSe)

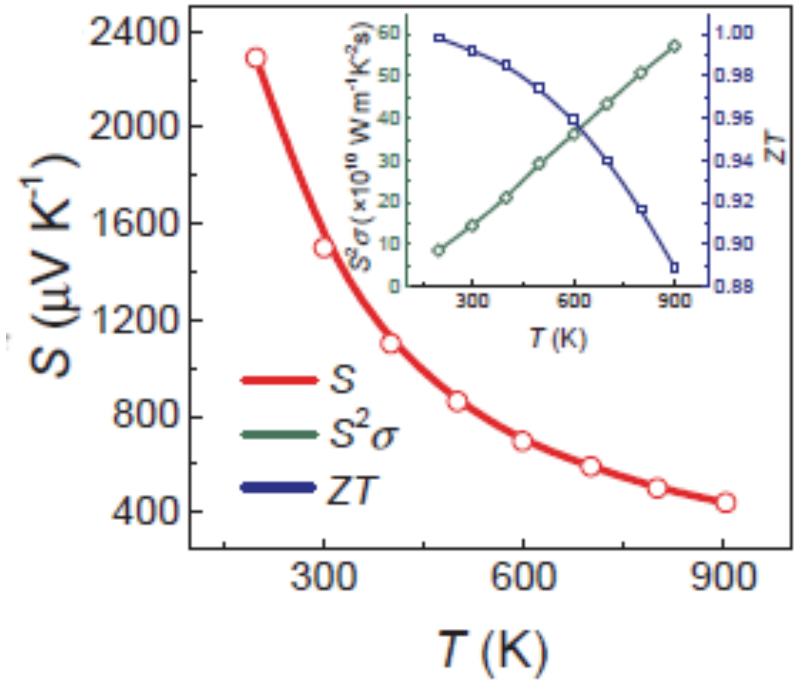
Orthorhombic
a = 11.49 Å
b = 4.16 Å
c = 4.46 Å



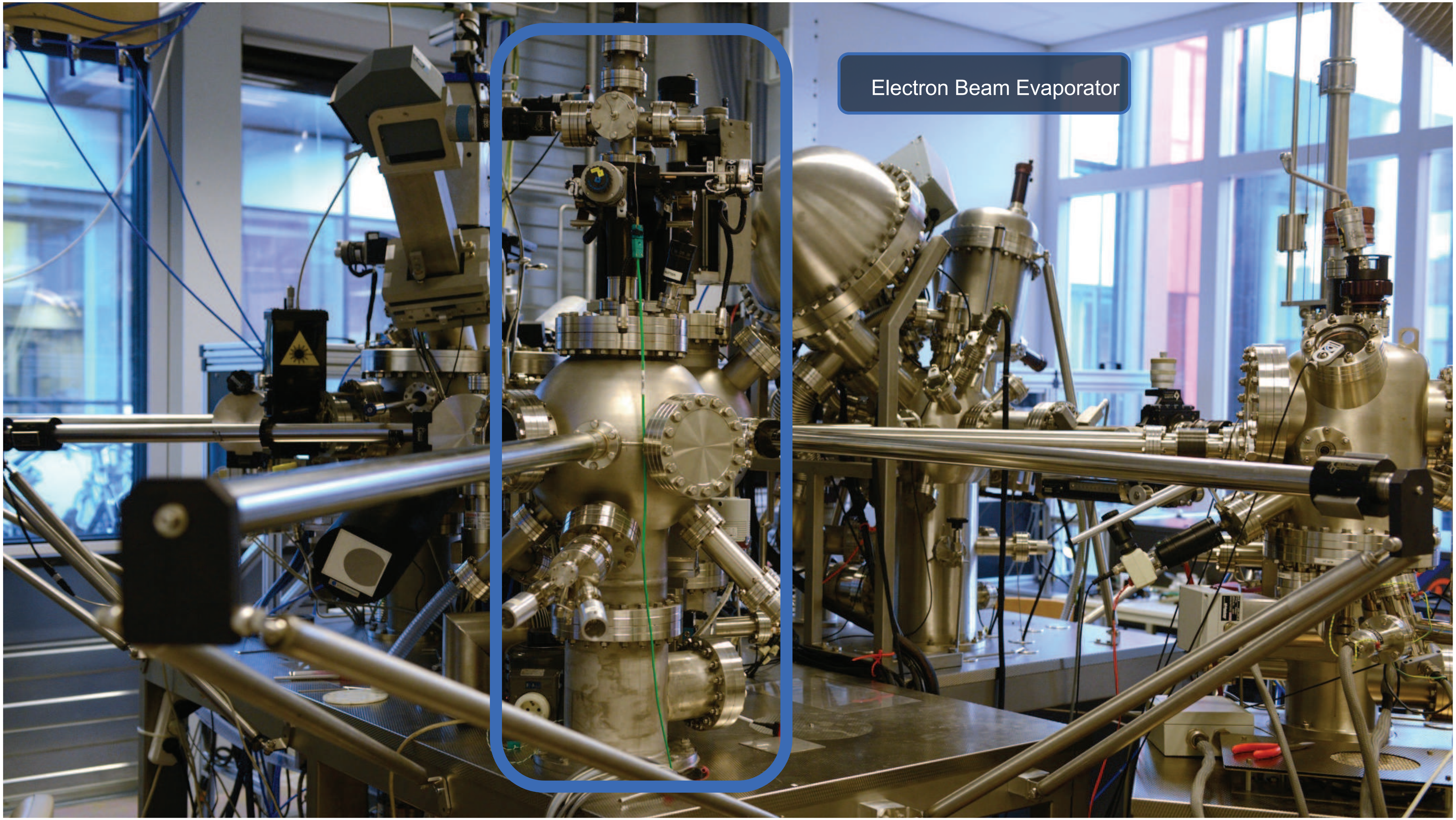
Zhao, L.-D., et al. (2014). Nature **508**: 373.

Cubic
a = 11.97 Å

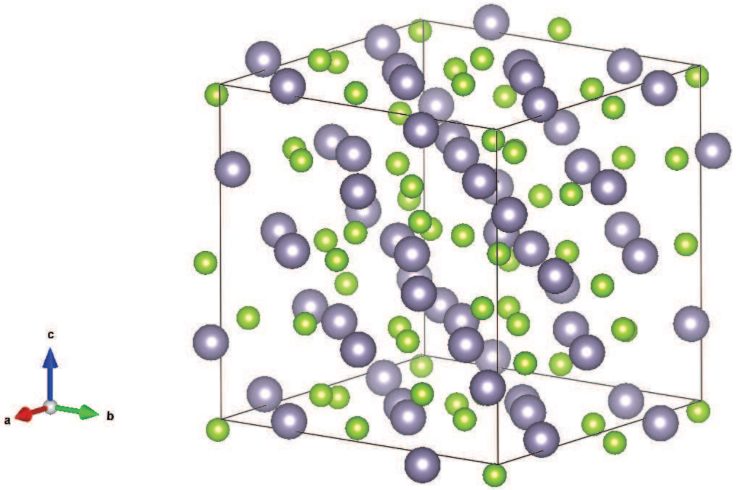




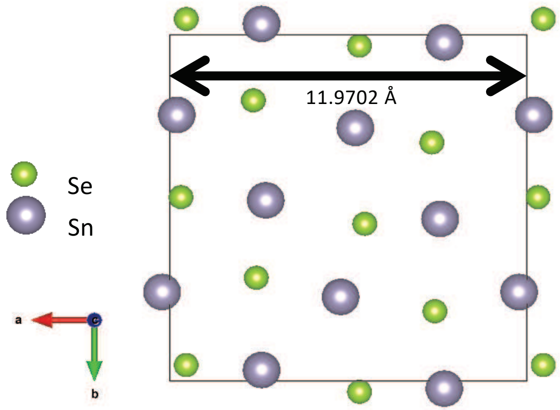
Butt, F. K., et al. (2017). Journal of Alloys and Compounds **715**: 438-444.


Electron Beam Evaporator

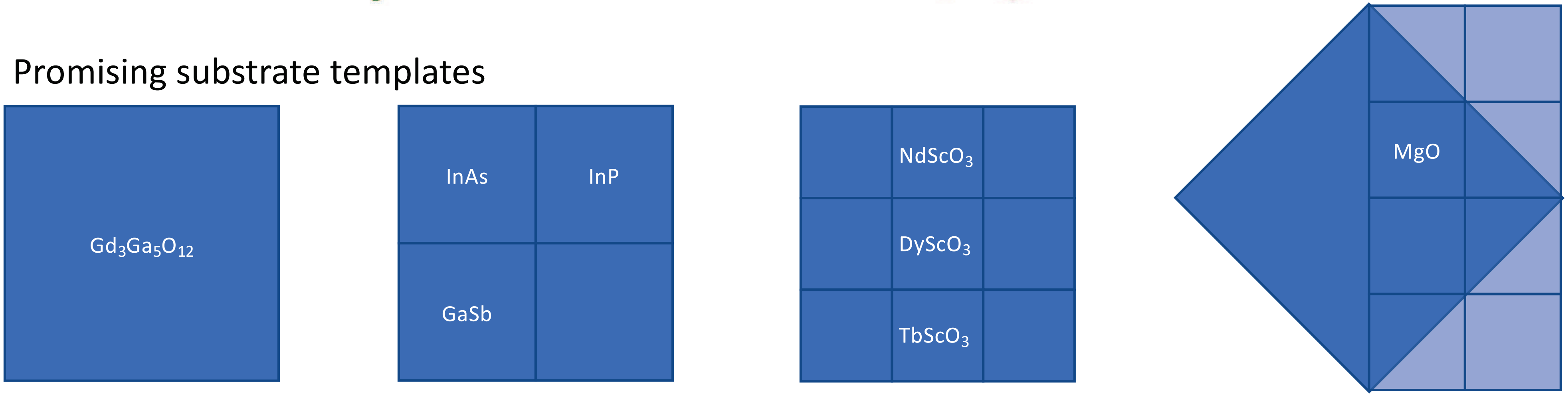
Epitaxial thin film engineering



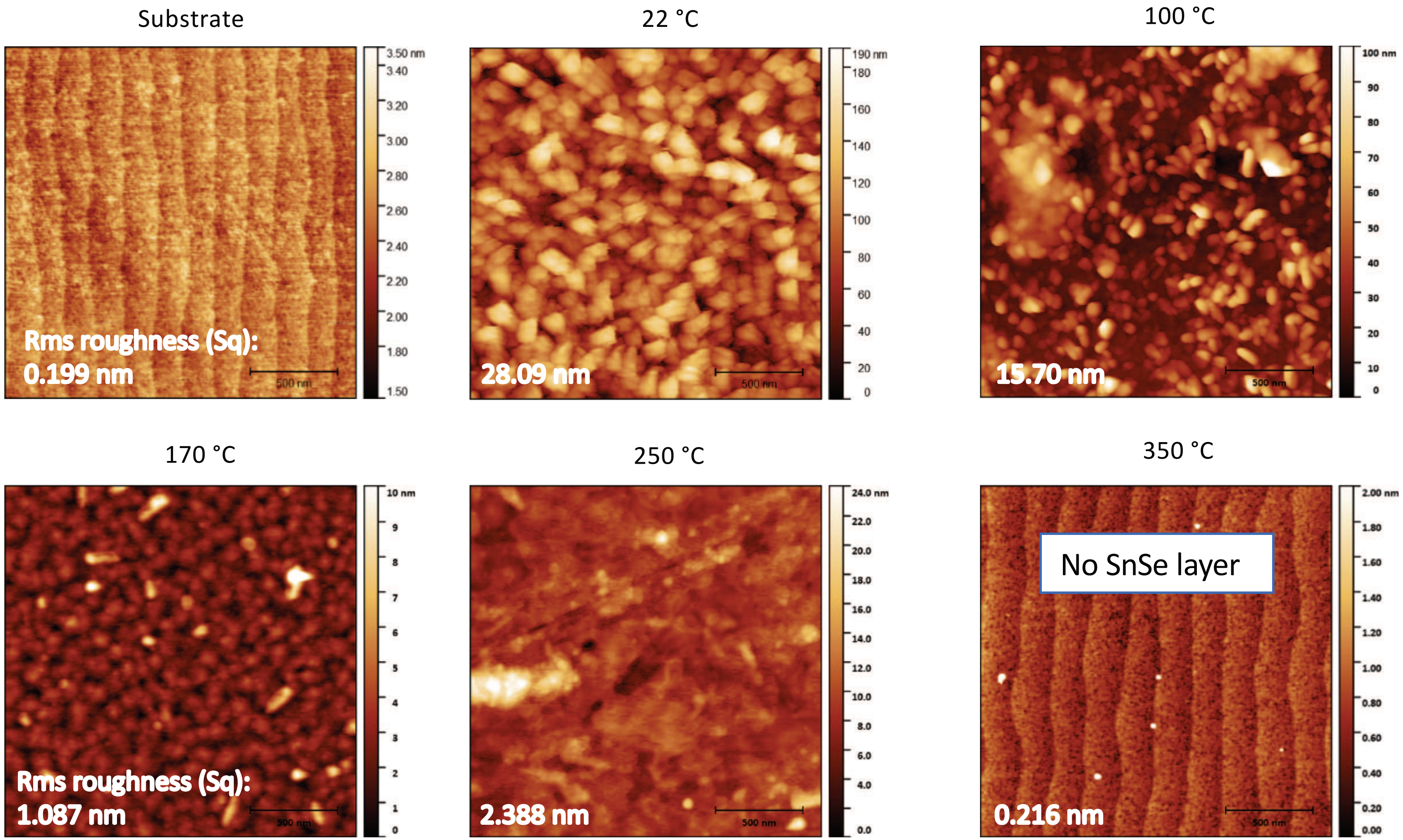
Cubic SnSe – (100) surface



Promising substrate templates

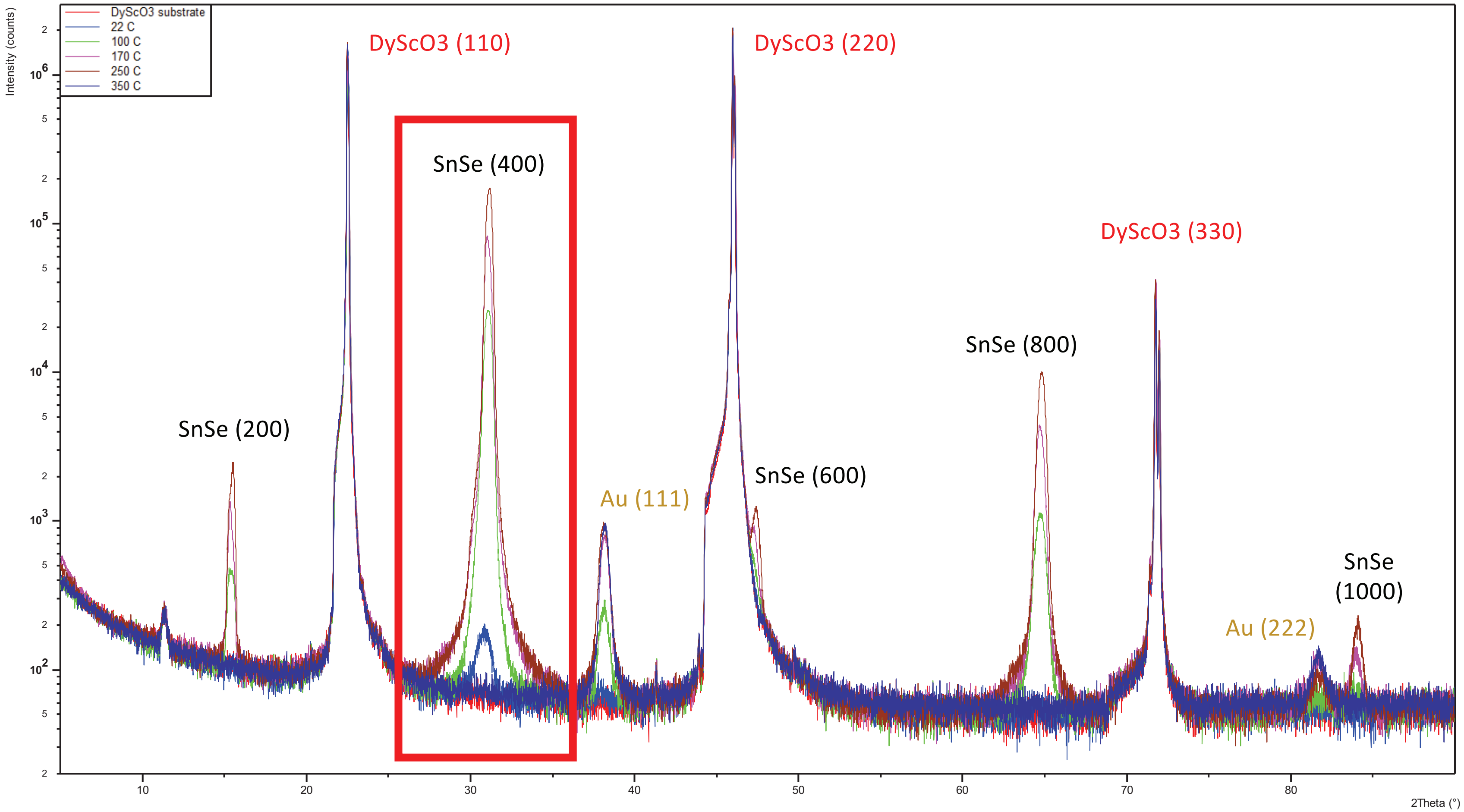


SnSe thin film growth: temperature dependence



$DyScO_3$ (110) substrate

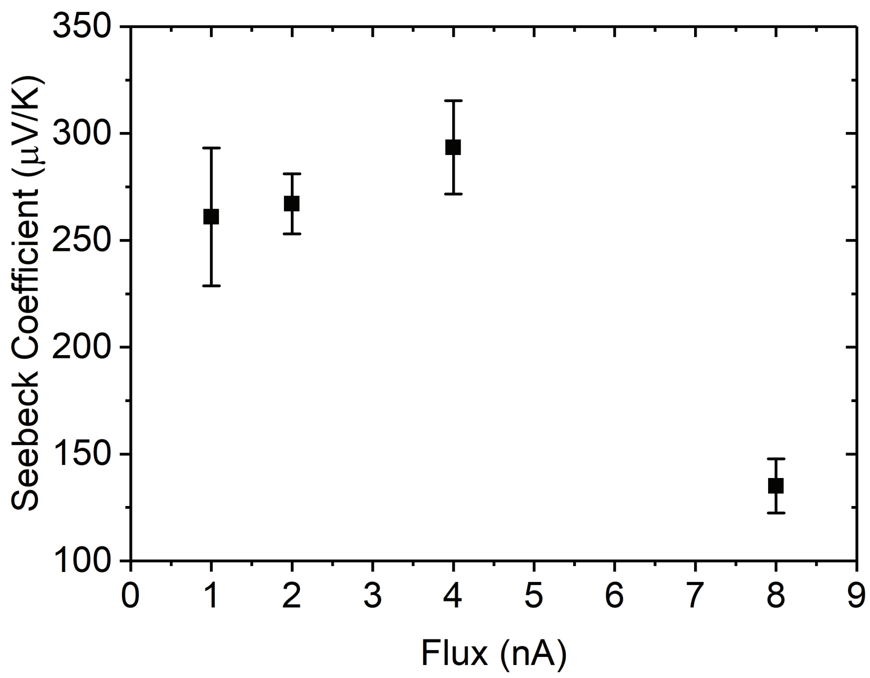
SnSe thin film growth: temperature dependence



Thermoelectric Properties

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

Seebeck Coëfficient



σ

0.5 - 1.9 S/cm

This value is comparable to literature

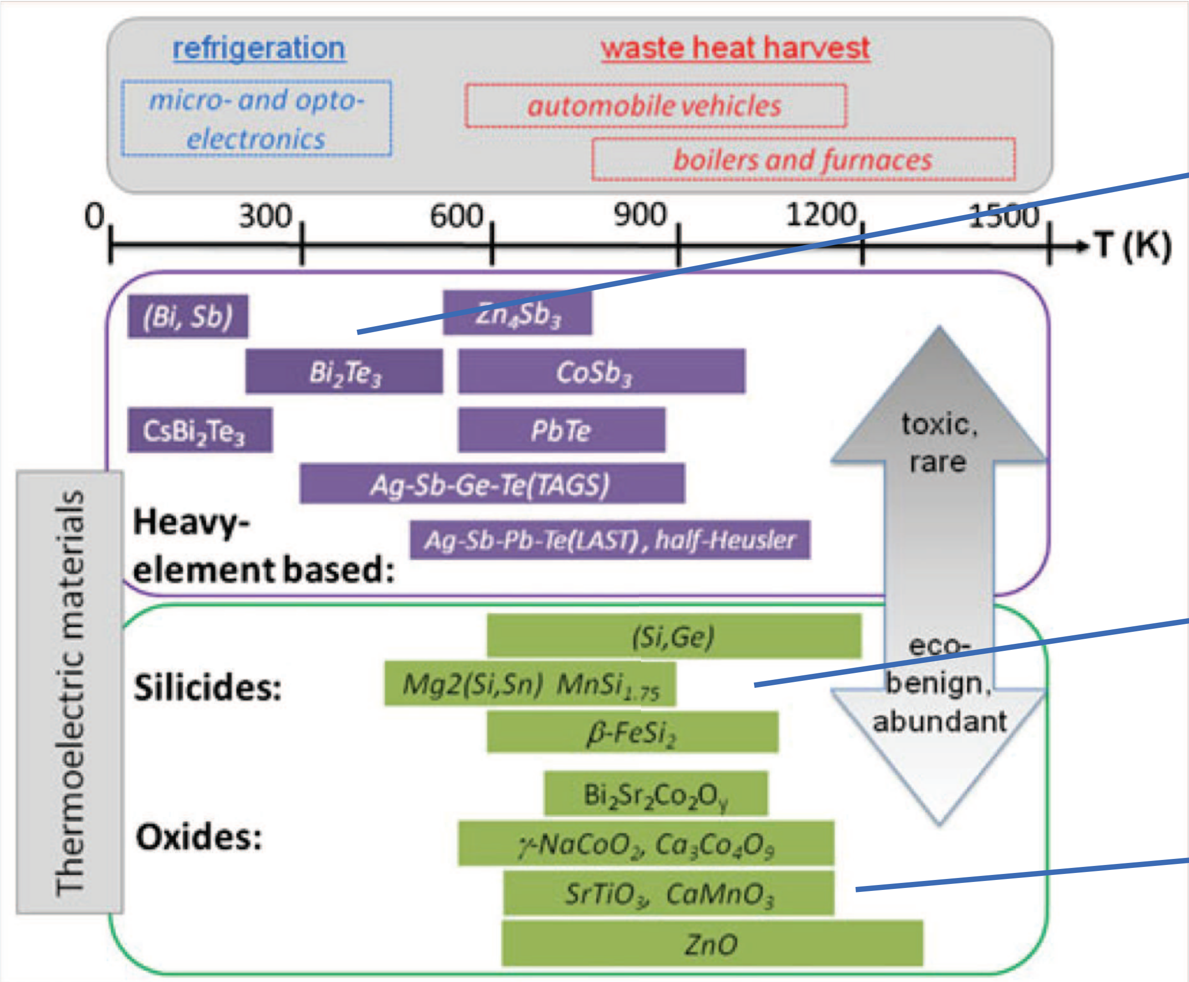
We are currently expanding the measurement capabilities

κ

Radboud Universiteit

Time Domain Thermo Reflectance

Advanced Thin Film Technology for Thermoelectrics



SnSe

$MnSi_{1.7}$

$NaCoO_2$ and $Ca_3Co_4O_9$

$Sr_{1-x}La_xTiO_3$

J. He *et al.*, *J. Mater. Res.* **26**, 1762 (2011).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Thank you