Boosting room-temperature thermoelectricity in $SrTiO_3$ based superlattices

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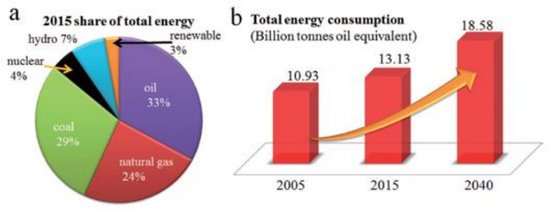
Motivation

Urgent Energy Crisis [1]

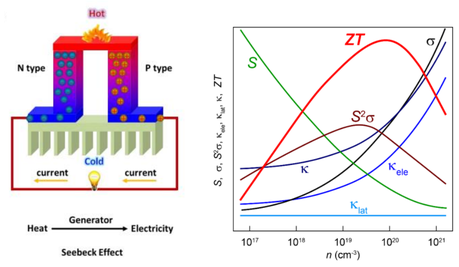
Thermoelectric materials have the capability of converting waste heat into electricity.



Lei Yang et al, Adv. Energy Mater. 8 (2018)

Figure-of-merit[2]

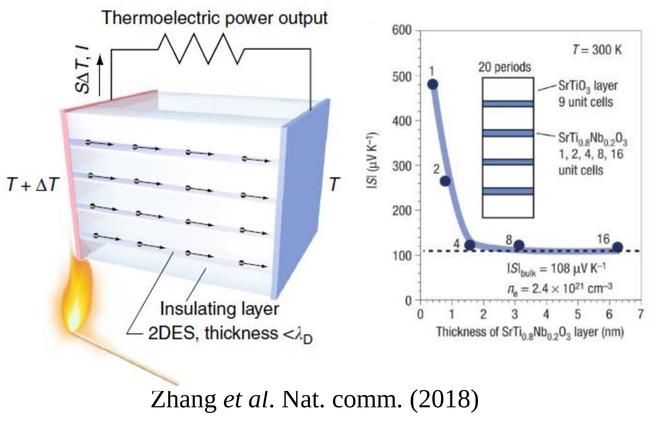
$ZT = \frac{S^2\sigma T}{\kappa}$ "phonon-glass electron-crystal"



Zhang, Yuqiao. PhD diss., Hokkaido University, (2019)

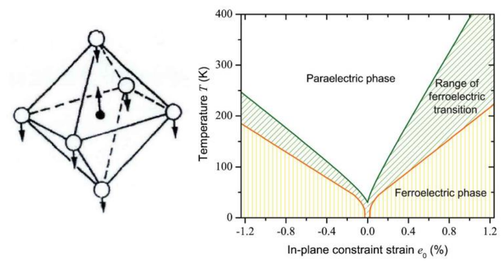
➢ How to decouple the correlation and improve *ZT*?

Quantum well effect [3]



Zhang *et al*. Nat. comm. (2018)

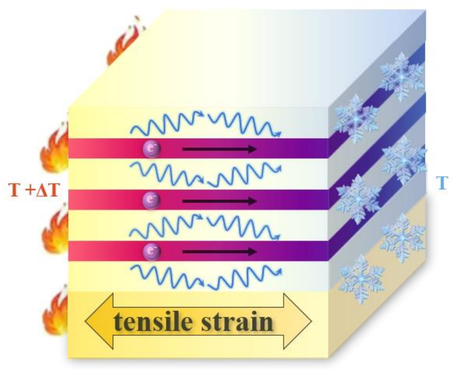
Ferroelectric Phase Transition in strained STO[4]



J. H. Haeni et al, Nature,430(2004)

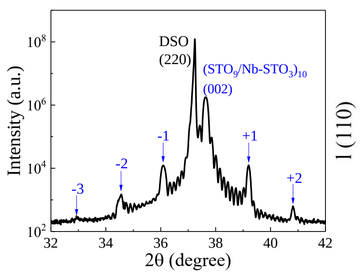
$[(STO)_9/(Nb\text{-}STO)_3]_{10}$ superlattices

Ideal configuration

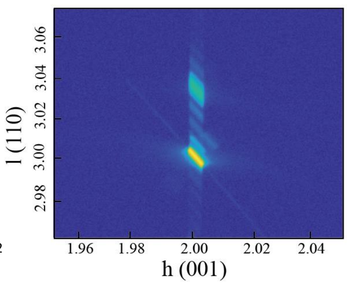


Fabrication of superlattices

XRD

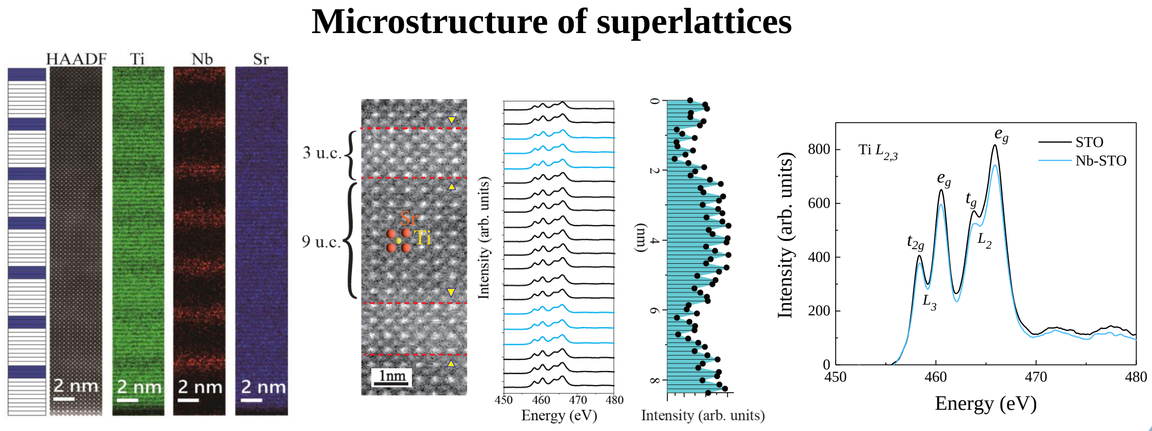


RSM



➢ **Artificial superlattices separate the phonon/electron layers.**

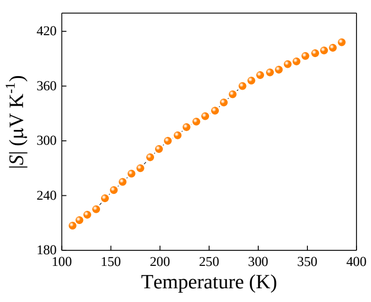
Microstructure of superlattices



Thermoelectric properties

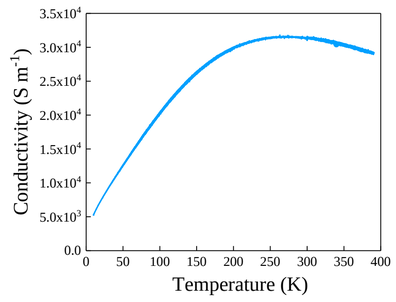
Seebeck Coefficient

The $|S|$ value reaches 372 μV K^{-1} at room temperature, which is 3.4 times larger than that of the bulk Nb-STO.



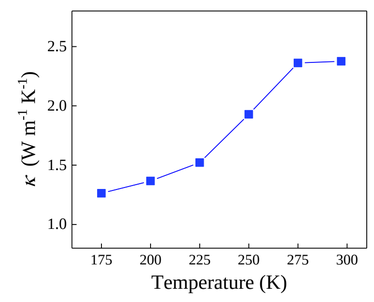
Electrical Conductivity

Enhance the electrical conductivity of the superlattices under compressive strain.



Thermal Conductivity

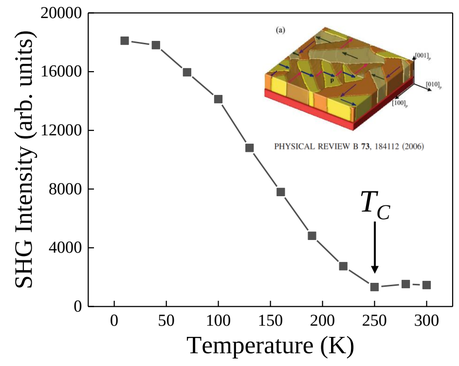
Thermal conductivity reached 2.4 W m^{-1} K^{-1}, which is dramatically lower than that of STO bulk material.



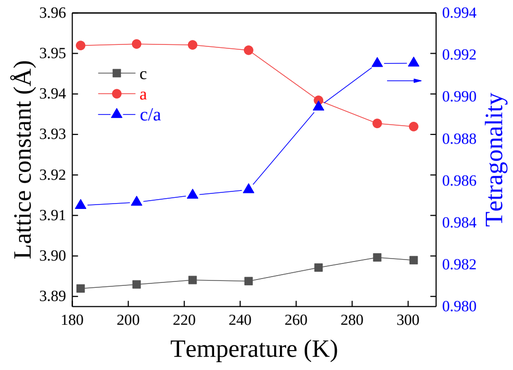
➢ **Combined the measured electrical with thermal properties, the maximum ZT value is reached at room temperature exceeding 0.51.**

Ferroelectric transition

SHG

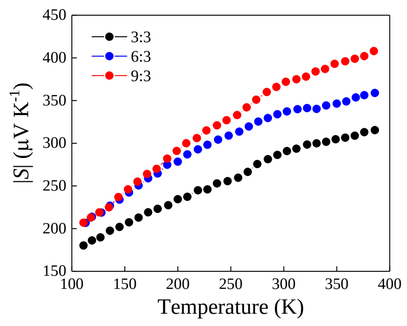


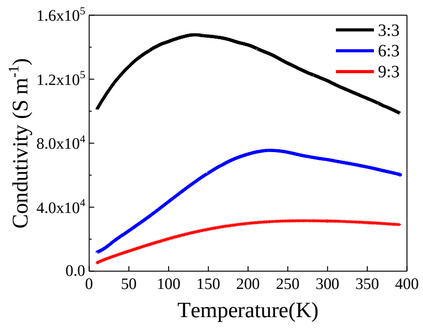
Temperature-dependent XRD

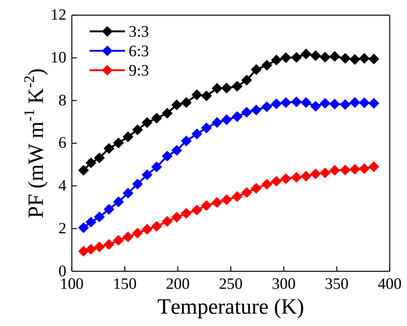


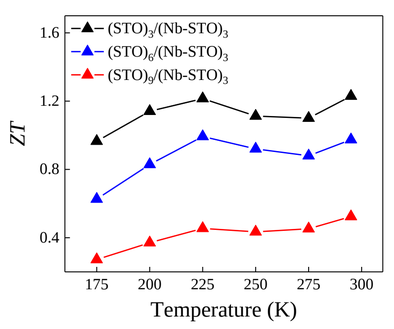
➢ **FE transition soften the phonon modes and enhance phonon scattering.**

Further improve *ZT*









➢ **Reduction of insulating layers increases the electrical conductivity and further boosts the thermoelectric performance.**

Outlook

- Introducing tensile strain into STO based superlattices increases the ferroelectric transition temperature leading to phonon-softening at elevated temperatures, which in turn improves their room temperature thermoelectric properties.
- A large ZT value of 1.2 has been achieved at room temperature for the $[(STO)_3/(Nb\text{-}STO)_3]_{10}$ superlattice, which is highly competitive in STO-based thermoelectric materials.