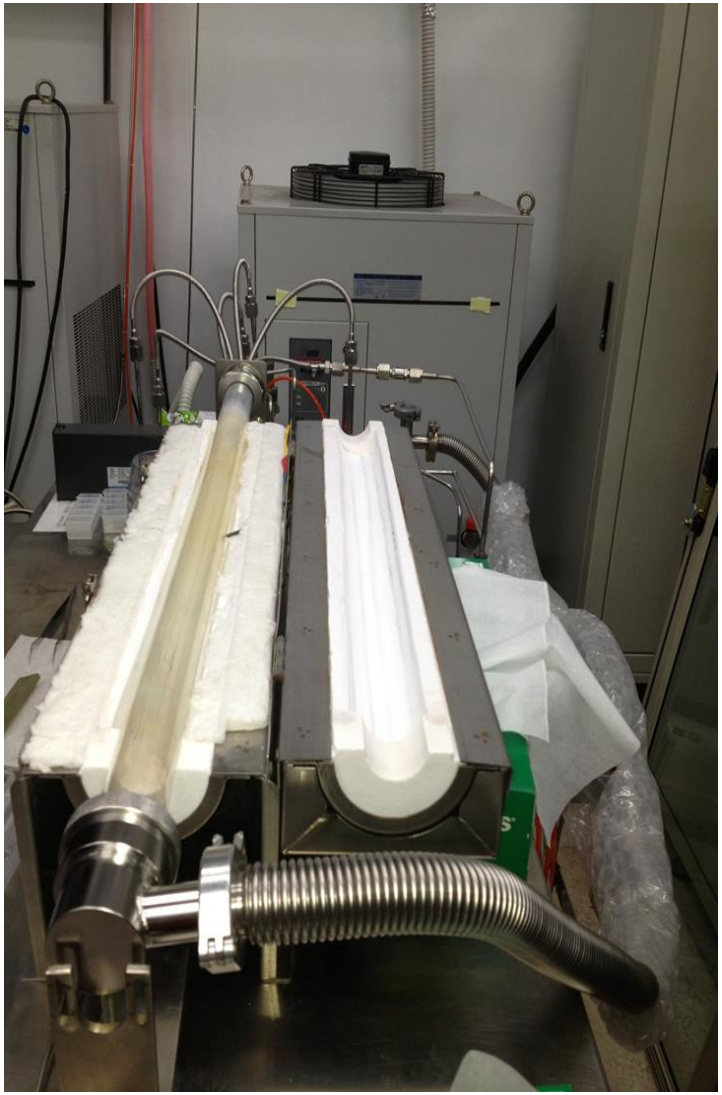
Atomic Layer Deposition (ALD)

- This technique is a thin film deposition technique.
- By keeping the precursors separate throughout the coating process, atomic layer control of film growth can be obtained as fine as ~0.1 Å (10 pm) per cycle.
- Application: Atomic layered - Metal oxides, such as Zinc Oxides(ZnO) and Aluminum Zinc Oxide(AZO).



RF Sputter machine

- Application: Deposition of metallic layers (Cu, Zn, Sn), and metal oxide layers(ITO, ZnO).

Selenization Chamber

- Application: CIGS, CZTSe, CIS Solar Cells.

Electron cyclotron resonance plasma enhanced chemical vapor deposition (ECR CVD)

In semiconductor industrial, ECR-CVD is widely used for preparing dielectric film and for patterned etch purpose. The advantages of the ECR-CVD system are a high plasma density at low-pressure conditions in the mTorr-range.

- **Materials prepared in our lab using ECR-CVD (some examples)**:
- Preparation of polycrystalline SiCN film [1]
- Preparation of nanotips array template for various application
- Different materials with nanotips structure were prepared, such as single-crystal silicon (Si); polycrystalline silicon (poly-Si); epitaxial gallium nitride (GaN) film on sapphire; single-crystal gallium phosphide (GaP); sapphire; and aluminum.[2]

Electron cyclotron resonance plasma enhanced chemical vapor deposition (ECR CVD)

- For various application:

(1)Field emission [3]

(2)Broad-band antireflection (Vis-IR) $R << 0.1\ \%$[4]

(3) High potential in molecular sensing via SERS was demonstrated. [5]

(4)Electrically driven light emission under a low voltage in nanotip LED. [6]

- [1] Kuei-Hsien Chen et al., Thin solid films 355, 205 (1999).
- [2] Chih-Hsun Hsu et al., Nanoletter 4, 471 (2004).
- [3] Hung-Chun Lo et al., Appl. Phys. Lett. 83, 1420 (2003).
- [4] Yi-Fan Huang et al., Nature Nanotechnology 2, 770 (2007).
- [5] Surojit Chattopadhyay et al., Chem. Materials 17 (3), 553 (2005).
- [6] Ya-Ping Hsieh et al., Nanoletter 9, 1839 (2009).

Thermal CVD

Application : Growth of III-V semiconductor materials, such as GaN.

Or provide inert atmosphere(Nitrogen, argon) annealing process.

ZEM-3

Seebeck effect
(Power generation application)
$S=\Delta V/\Delta T$

Peltier effect
(Cooling application)

Measure Seedback coefficient and thermal conductivity coefficient

ZT Figure of Merit

$$ZT = \frac{S^2 \sigma T}{\kappa_{lattice} + \kappa_{electronic}}$$

Electron - Phonon

S Seebeck Coefficient = ΔV/ΔT

High in Crystalline Semiconductor

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

Carrier Concentration Tuning

σ Electrical Conductivity

High in Crystalline Metal

$$\sigma = ne\mu = \frac{ne^2\tau}{m^*}$$

Band Structure Engineering

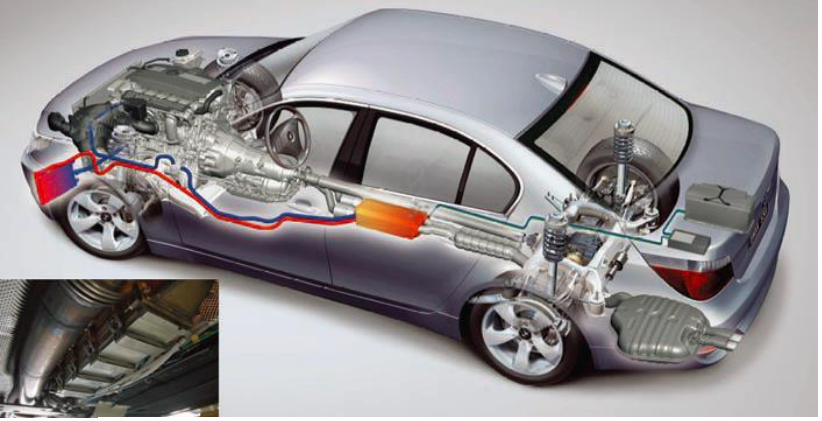
κ Thermal Conductivity

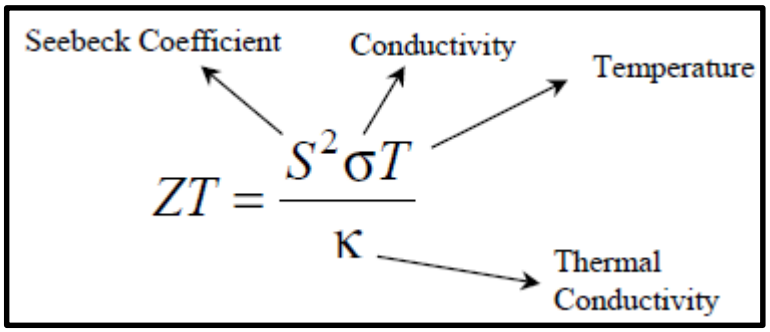
Low for glass

$$\kappa = \kappa_l + \kappa_e$$

$$\kappa_{lattice} = \frac{1}{3}(C_v v_s \lambda_{ph})$$

$$\kappa_{electronic} = \sigma LT$$





$$\varepsilon = \frac{T_H - T_C}{T_H} \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_C}{T_H}}$$

T_{H1}=500K, T_{H2}=800K, T_C=RT=300K, ZT=4

Ɛ=17.4% ~ 29.6%

Engine temperature 500K~800K

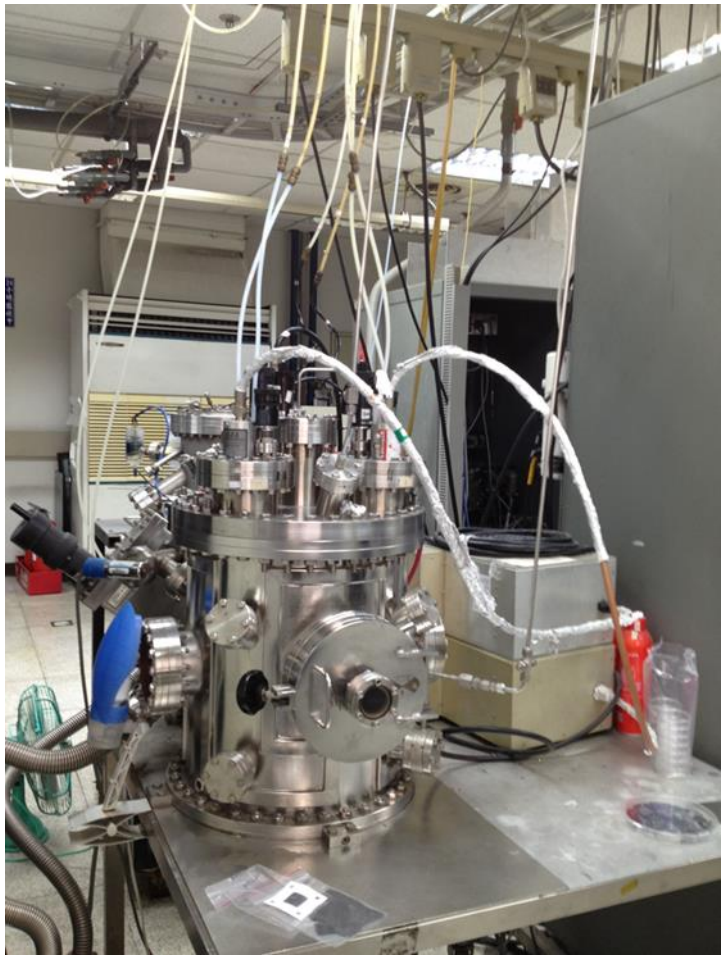
Carnot efficiency
Thermodynamic limit
ZT=infinity
ZT=20, unlikely
ZT=4, ambitious
ZT=2, plausible eventually
ZT=0.7, available today
Coal/Rankine
Solar/Brayton
Nuclear/Brayton+Rankine
Solar/Stirling
Nuclear/Rankine
Solar/Rankine
Cement/Org. Rankine
Geothermal/Kalina
Geothermal/Org. Rankine
Efficiency (%)
Heat source temperature (K)
0
10
20
30
40
50
60
70
80
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300

Assessing thermoelectrics. Efficiency of 'best practice' mechanical heat engines compared with an optimistic thermoelectric estimate

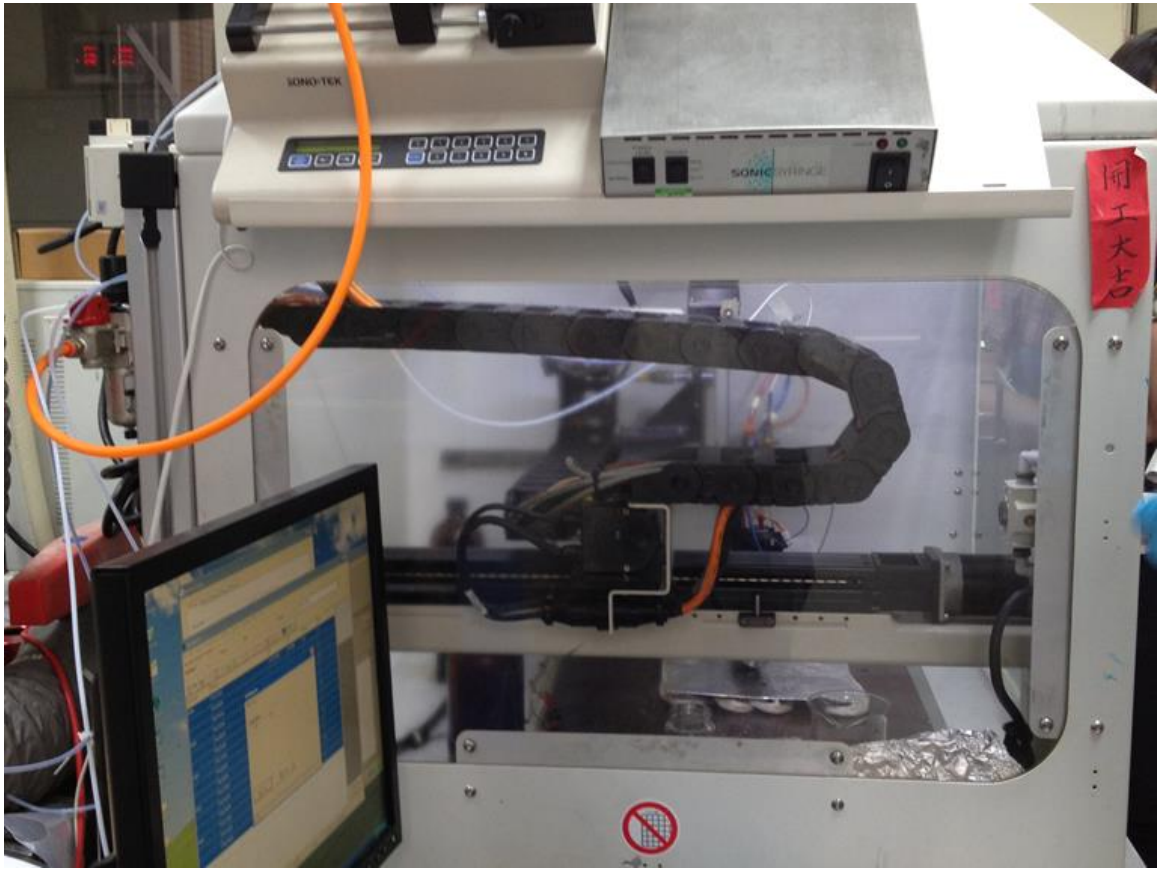
Ion-Beam Sputter

- Application: metallic and metal oxide layers.
- Provide uniform coating.

RF Sputtering



- Application: metallic and metal oxide layers.



Ultrasonic Spray

Application: Solution-based patterned, high uniformity thin film fabrication.