Thermal Management of Electronics – Energy Conversion Issues

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Drivers for Thermal Packaging

- Air as the Ultimate Heat Sink
- **Market-Driven Thermal Solutions**

  Price – volume – weight – reliability
- **Environmentally-Friendly Design**
  - **Low power consumption**
    - **Semiconductor devices**
    - **Packaging and cooling**
  - Low noise: acoustic and EMI
  - Recyclability
- Feature-Rich Design Tools
  - Integrated with product CAD system
  - Parametric optimization

Design for Sustainability

- "spreading" + natural convection/radiation
- Entropy generation minimization
- Least-material optimization
- Least-energy optimization

Work allocation factor, ξ_{pp}

= Pumping work/Total cooling work

$$= W_{pp} / [W_M + W_{PP}]$$

Design for Sustainability Metrics

- **Coefficient of Performance**

$$COP = q_T / IP$$

$$IP = V_{air} \times \Delta P$$

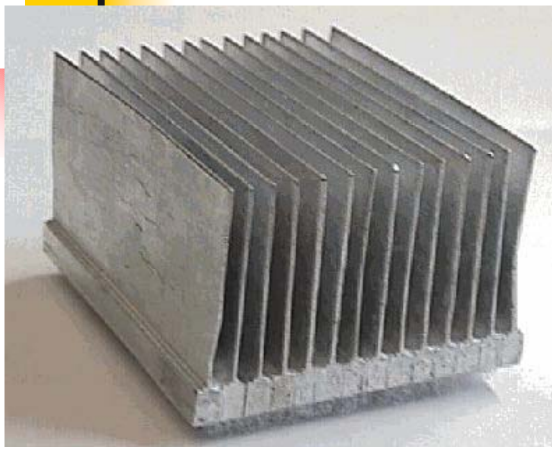
- **Total Work Coefficient of Performance**

$$COP_T = q_T t_1 / W_T$$

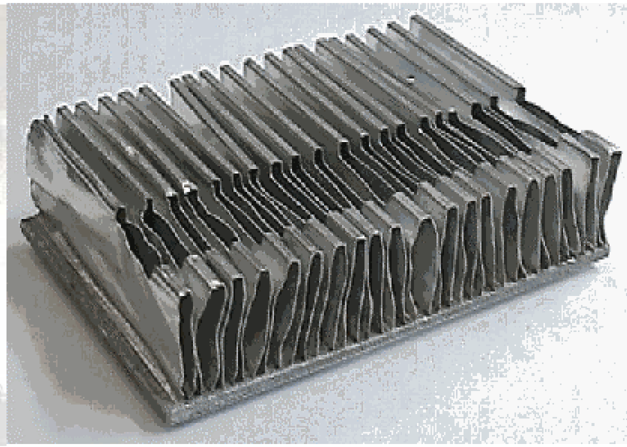
$$W_T = W_M + W_{PP}$$

$$W_M = 85\ M \quad \text{(aluminum-estimated)}$$

High Performance Heat Sink Arrays

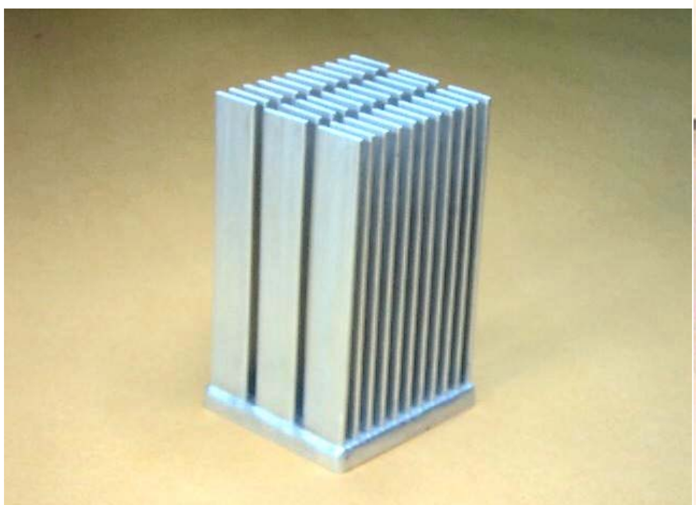


(a) Bonding

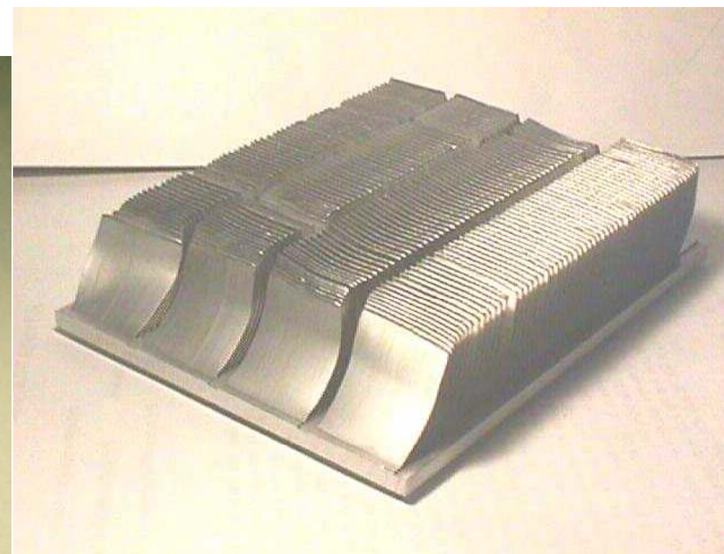


(b) Folding

(c)Modified Die-Casting



(d) Forging



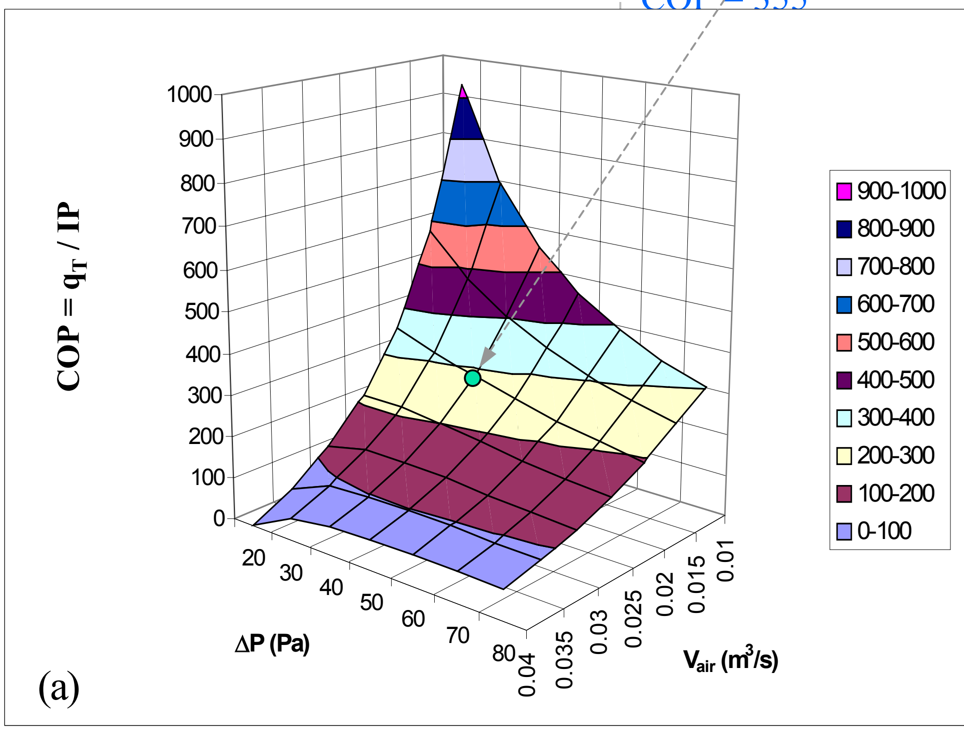
(e) Skiving

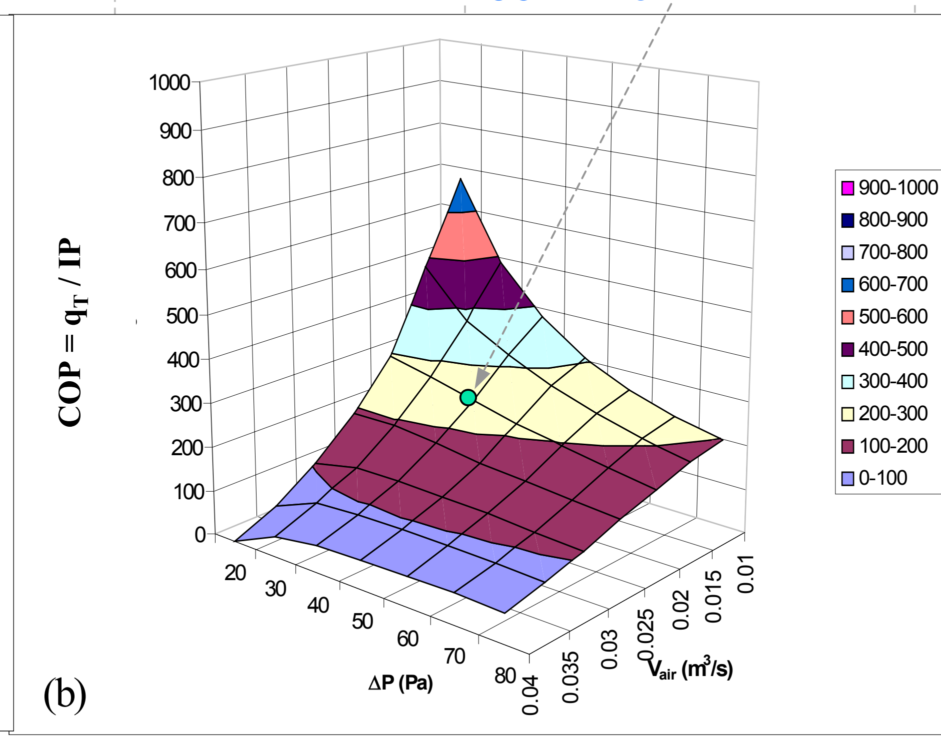
(f) Machining

Heat Sink
Coefficient of Performance

$\Delta P = 40 Pa$, $V_{air} = 0.02\ m^3/s$
$q_T = 284 W$, $IP = 0.8 W$
$COP = 355$

$\Delta P = 40 Pa$, $V_{air} = 0.02\ m^3/s$
$q_T = 194 W$, $IP = 0.8 W$
$COP = 243$





Maximum heat transfer design

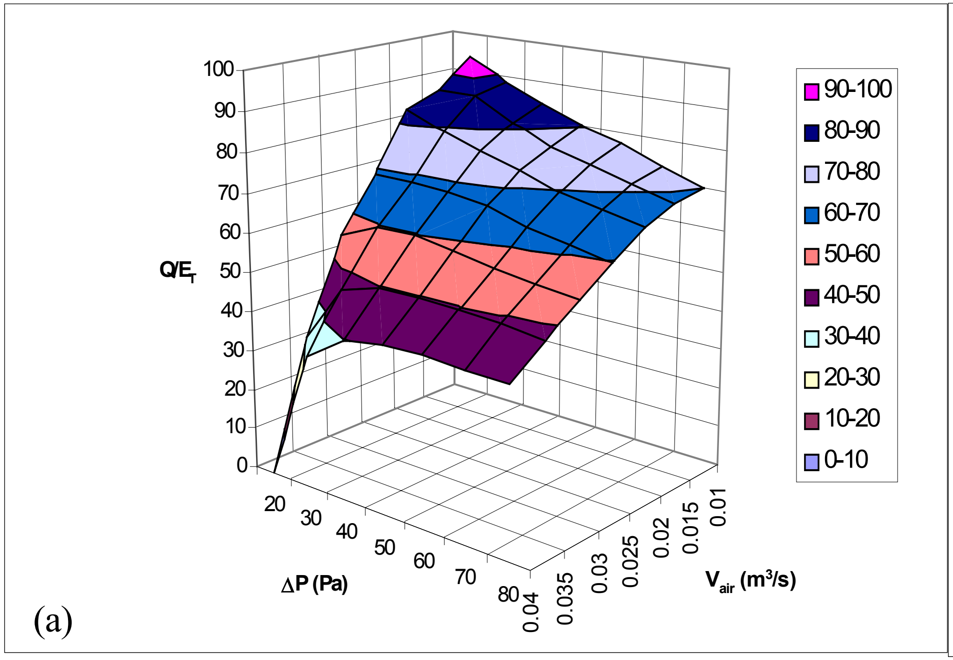
Least material design

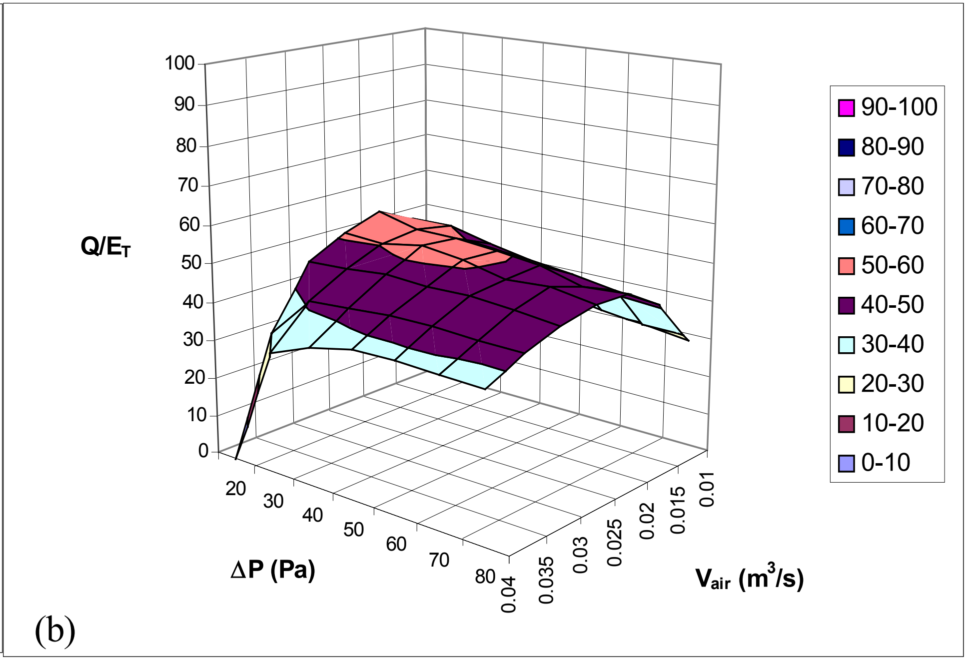
$L = W = 0.1\ m$, $H = 0.05\ m$, $\theta_b = 25\ K$, $k = 200\ W/m\text{-}K$

COP_T Comparison

Forced convection SISE plate-fins

L= W = 0.1 m, H = 0.05 m, θ_b= 25 K, k = 200 W/m-K





Least material design

Maximum heat transfer design

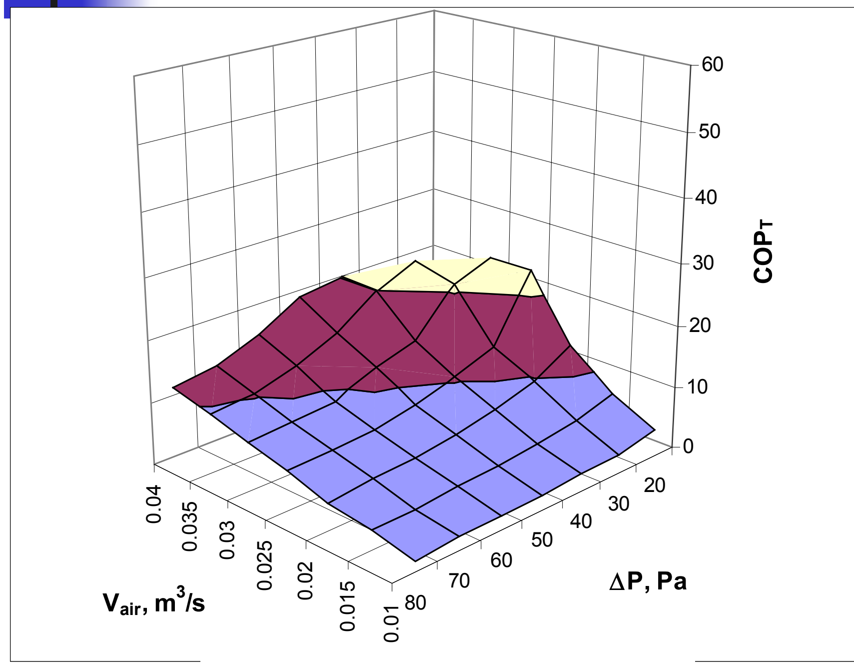
$$COP_T = q_T t_1 / W_T$$

$$W_T = 85 M + IP\, t_1$$

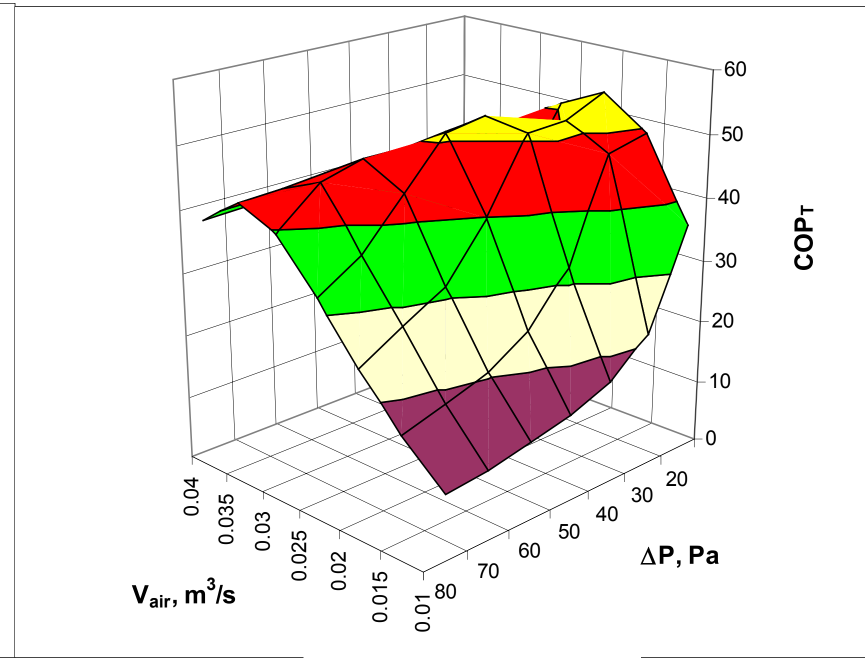
COP_T Comparison

Forced convection SISE plate-fins

$L = W = 0.1$ m, $H = 0.05$ m, $\theta_b = 25$ K, $k = 200$ W/m-K



(a) COP_T, **Extrusion**



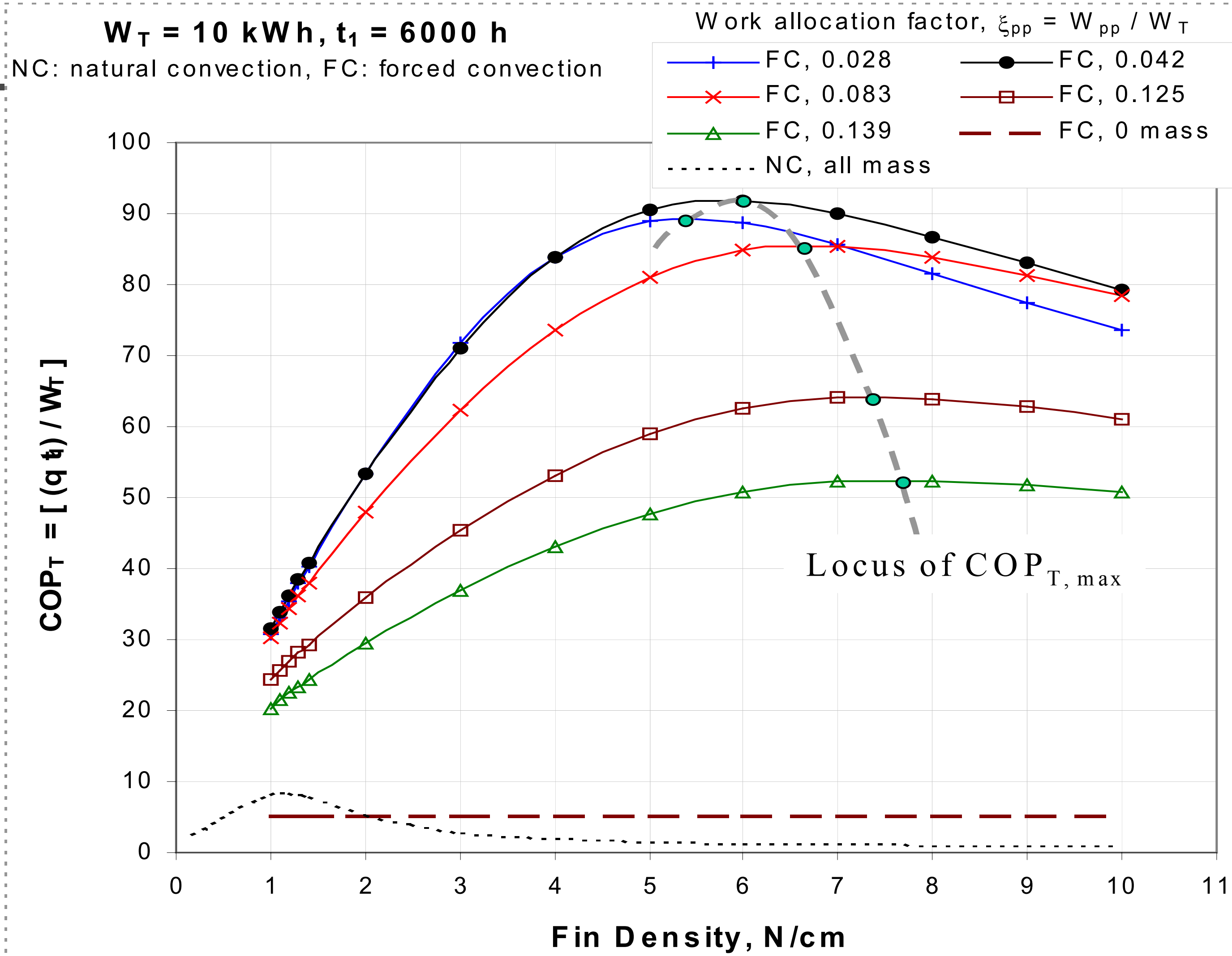
(b) COP_T, **Skiving**

$$COP_T = q_T t_1 / W_T$$

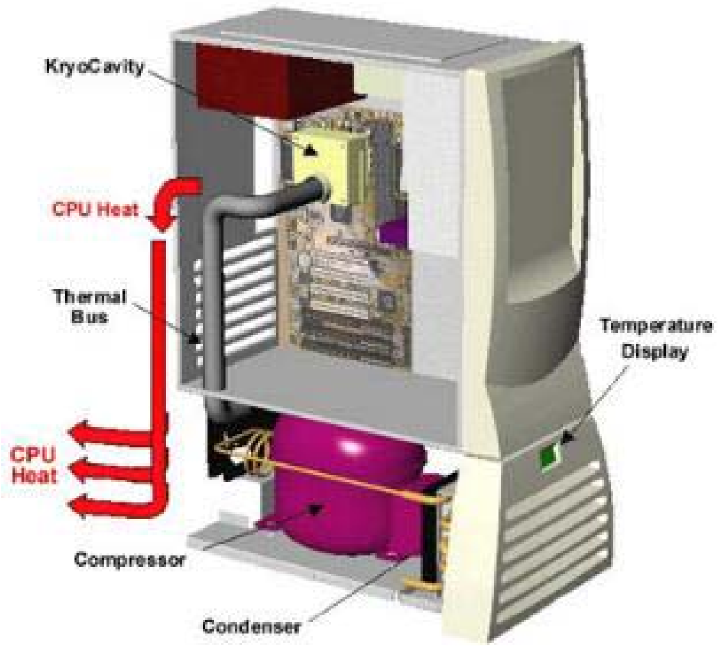
$$W_T = 85\,M + IP\ t_1$$

COP_T Optimization

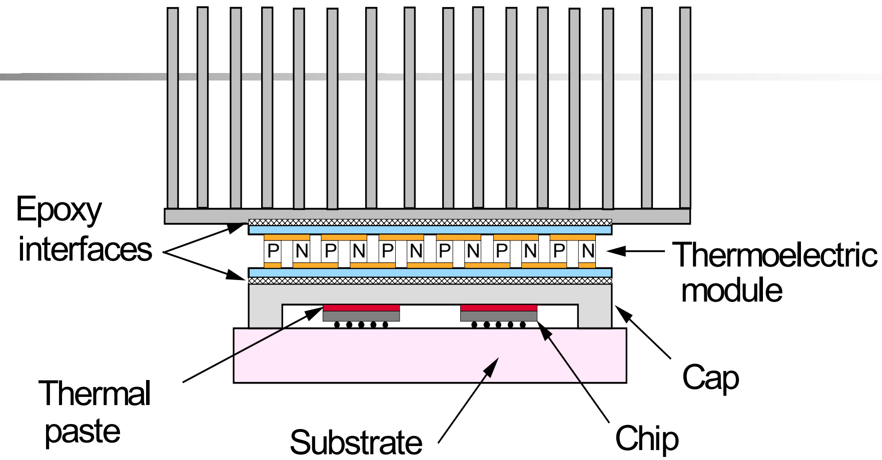
SISE plate-fins, W_T = 10 kWh, t_1 = 6000h

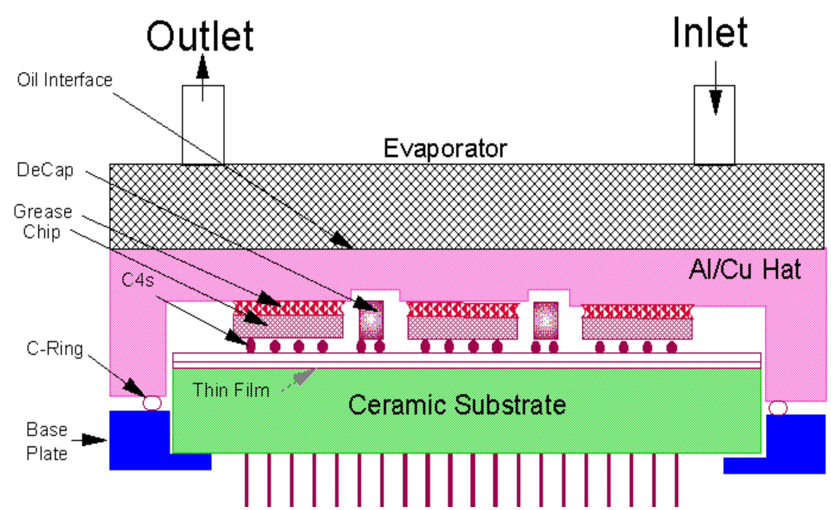


Refrigeration Technologies for Microelectronics



Kryotech





IBM S/390 G4

Issues in Refrigerated Packaging

- CMOS Chip/CPU Performance
- Performance Driven by" Hot Spots"
- "Cost" of Refrigeration System
  - Life Cycle Cost
  - Volume, Mass
  - Power Consumption
- Reliability of Refrigeration/Packaging
  - Refrigeration Hardware
  - Condensation on PCBs + Refrigerant Lines
  - Vibration

Fundamental Thermal Packaging Research

- Low-cost, high-k packaging materials
- Low-cost, reliable PCM's
- **Enhancement of convection/boiling/spray**
- **Heat Sink/HX Manufacturing processes**
- **Compact liquid cooling/refrigeration systems**
- **Improved solid state refrigeration**
- **Low environmental impact systems**
- Integrated modeling tools

Concluding Thoughts

- **Growing energy consumption in electronic systems**
- **Thermal Management significant fraction of energy consumption**
- **Promise of local energy conversion**
- **Design for sustainability requires:**
  - **Passive cooling where feasible**
  - **Optimization of COP for active cooling**
  - **Optimization of COP_T for all systems**