Thermal Management of Power Electronics
Task at NREL

- **Goals**
  - Develop means to improve heat rejection from power electronics > 250 W/cm²
  - Reducing system cost, increasing reliability, specific power, power density, and efficiency

- **Objectives for FY04**
  - Develop and demonstrate the viability and advantages of two-phase cooling techniques such as spray cooling, and Jet impingement

- **Deliverable for FY04**
  - Technical report on viability of spray-cooling and jet impingement for high heat flux heat removal
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- **Task Description: 2-phase heat management**
  - Investigation of spray cooling fluid dynamics: droplet size and pattern, orientation, surface treatment, spray behavior in critical system pressure, heat load, and vibration ranges.
  - Investigation of jet impingement fluid dynamics: Jet nozzle design, orientation, surface treatment, jet behavior in critical system pressure, heat load, and vibration ranges.
  - Surface preparation studies
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High Heat Flux Thermal Management Techniques

- Pool Boiling/Thermosyphons (30-70 W/cm²)
- 2-phase Microchannel/Minichannel Cooling (100-250 W/cm²)
- Jet Impingement Cooling (70-110 W/cm²)
- Spray Cooling (80-120 W/cm²)
- Surface Enhancement
- Choice of Coolants
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- **Pool Boiling**
  - Coolant that boils 10 to 40°C below the operating temp.
  - 30-70 W/cm²
- Governing Parameters
  - Surface Enhancement
  - Surface Orientation
  - Nucleation Sites
  - Fluid Properties

![Pool boiling curves for a 12.7-mm heated disc in saturated FC-72 at different surface orientations (adapted from [18]).](image)
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- 2-Phase Microchannel/Minichannel Cooling
  - Require minimal coolant flow rates
  - Flow channels with dimensions ranging from hundreds of microns to few millimeters
  - 100-250 W/cm²
  - Governing Parameters
    - Microfabrication methods
    - Pressure drop
    - Choice of hydraulic diameter
    - Fluid Properties

Fig. 18. Comparison of microchannel and minichannel heat sink characteristics relative to (a) cooling performance and (b) pressure drop (adapted from 1)
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**Jet Impingement Cooling**
- Free jet (vapor or gaseous environment)
- Submerged jet (liquid jet in liquid environment)
- Confined jet (liquid jet confined between the nozzle and target)
- Aggressive form of cooling (large impact momentum)
- 70-110 W/cm²

**Governing Parameters**
- Jet velocity
- Jet diameter
- Subcooling of working fluid
- Fluid Properties

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*Fig. 21. Free circular jet boiling curves for different flow rates (adapted from [67]).*
Spray Cooling

- Water or FCs
- 80-120 W/cm²
- Governing Parameters
  - Droplet Diameter
  - Surface Orientation
  - Surface Texture
  - Fluid Properties
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- Surface Modification Investigations
  - Grooved Surface Configurations
  - Dimpled Surface Configurations
  - Patterned Structure Configurations
- Spray Orientation Effects on Modified Surfaces
- Generally Focus on Thermal Effects On Underside of Die/Substrate
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- FC-72 used in initial modeling
- Mass flow rate 0.0084 kg/s
- Chip surface area 161 mm²
- Conditions match those in the literature
- Heat transfer now through droplet impingement, evaporation to be incorporated
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- Chip surface
- FC-72 spray
- Plain spray nozzle

Velocity magnitude (m/s)
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FC-72 spray

Wall jet

Mounting plane

30° segment of chip

Contours of celsius (Time=3.5140e-02)

Feb 12, 2004

FLUENT 6.1 (3d, segregated, spe2, rke, unsteady)
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Nonuniformities in spray pattern, interaction with wall jet lead to temperature variation.

Chip edge

Chip center
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- NREL’s Experimental Capability
  - Spray and jet impingement cooling testing capability, localized heat source and total inverter box
  - High speed camera for flow visualization
  - Infrared camera for temperature distribution