Thermal Management of High-Power Electronic Systems

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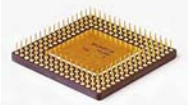
Cooling of High-Power Electronic Systems

Lasers | Radar | Military and space applications



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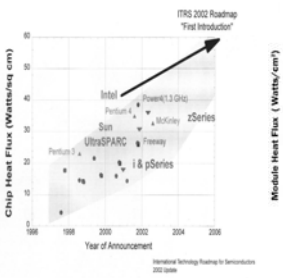
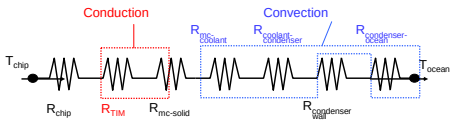
Computer chips and other electronic devices have ever increasing heat fluxes. Reliability and performance are greatly improved if they are maintained at low temperatures

Increasing Trends in Power Dissipation in Electronic Systems



Challenges

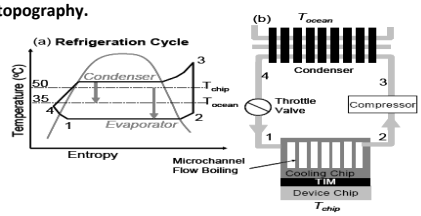
- **Accommodating ultra-high heat fluxes (>1000 W/cm²) at low wall temperatures (< ~65 °C).**
- **Reducing the magnitude of the three convective resistances in the thermal circuit.**



Simplified thermal circuit of complete thermal management system

Objectives

- **Understand governing processes of flow boiling and condensation in refrigerants (e.g., R-134a) at the microscale using experimentation and modeling.**
- **Enhance heat transfer (increase maximum heat flux and heat transfer coefficients) using this understanding by modifying microdomain configurations, surface chemistry and surface topography.**



Current Technology

Thermal Conductance		State-of-the-art	Target
Device Substrate Conductance	(MW/m^2-K)	0.10	5.00
Interface Conductance	(MW/m^2-K)	0.10	5.00
Microchannel Base Conductance	(MW/m^2-K)	0.10	5.00
Convective Conductance of Microchannel	(MW/m^2-K)	0.05	0.20
Cooling fluid-Condenser Conductance	MW/K	0.06	0.18
Condenser Sea Water Conductance	MW/K	1.65	4.94
Condenser wall Conductance	MW/K	0.12	0.37

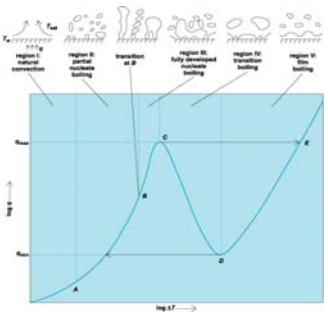
Operating Condition (1000 W/cm²)	Temperature of the device (°C)
Current state-of-the-art	560
With target conductances and without refrigeration	99
With target conductances and refrigerant temperature of 15°C	65

$Q = hA\Delta T$

$q = Q/A = h\,\Delta T$

To reach desired heat fluxes we must increase not only h but the $h\,\Delta T$ product.

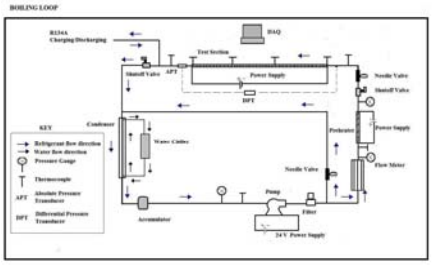
Boiling Heat Transfer Characteristics



- **Boiling results in higher heat transfer coefficients.**
- **Point C indicates critical heat flux (CHF) condition.**
- **At CHF the wall is in contact with vapor layer only and heat transfer rate drastically decreases.**
- **Increasing heat transfer coefficient and higher CHF value enables maximum heat removal most efficiently.**

THIS CURVE IS FOR POOL BOILING

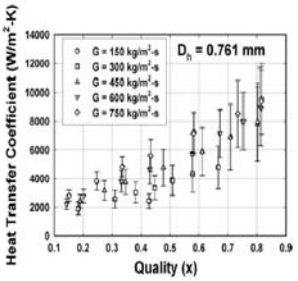
Experimental Apparatus (Boiling)



Initial experiments will be with straight circular tubes with diameters ranging from 178 to 1600 μm. Future experiments will involve other geometries (as described below).

Importance of Condensation

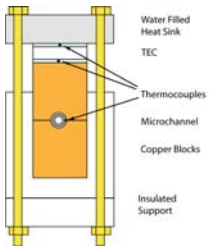
- **Condenser an essential component of vapor compression cycle**
- **High heat transfer coefficients needed for compactness**
- **Current experimental techniques give heat transfer coefficient uncertainties of ~40%**



Todd M. Bandhauer, Akhil Agarwal, Srinivas Garimella, 2006, Measurement and Modeling of Condensation Heat Transfer Coefficients in Circular Microchannels, Journal of Heat Transfer, Vol. 128, pp 1050-1059

A New Approach to Obtain Condensation Heat Transfer Coefficients

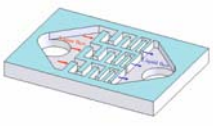
- **Traditional condensation experiments use fluid cooling**
- **This experiment uses thermoelectric coolers (TEC); electric power much easier to measure than enthalpy change of coolant**
- **Improve heat transfer coefficient accuracy to 10%**
- **Calculate pseudo-local heat transfer coefficients.**
- **Initial experiments will be will straight circular tubes (same as boiling test sections). Future experiments will involved other geometries (as described below).**



End view of test section

Enhancement of Flow Condensation

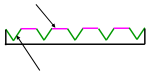
➢ **Enhancement of flow condensation with geometry/surface modifications**



Surface topography/ channel modification

Surface chemistry modification

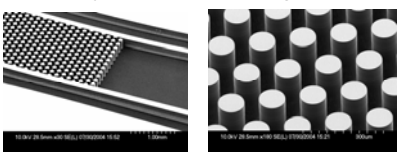
Super-hydrophobic

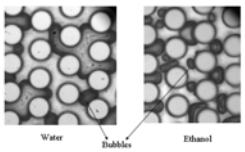


Super-hydrophilic

Micro Pin-fin Heat Sinks

- **Heat transfer enhancement (for boiling and condensation): silicon based micro pin-fin heat sinks (SEM images)**

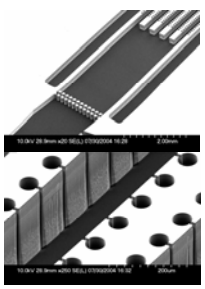


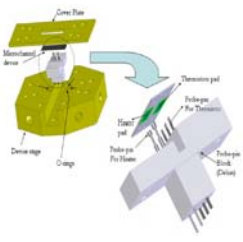


Bubbles flowing across 100 μm diameter pin fins entrenched in microchannel

Re-entrant Cavities

- **Boiling heat transfer enhancement: silicon based microchannels with re-entrant cavities**





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