Characterization and Development of Advanced Heat Transfer Technologies

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Project Duration: FY08 to FY10

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Advanced Power Electronics and
Electric Machines Projects
FY08 Kickoff Meeting

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This presentation does not contain any proprietary or confidential information

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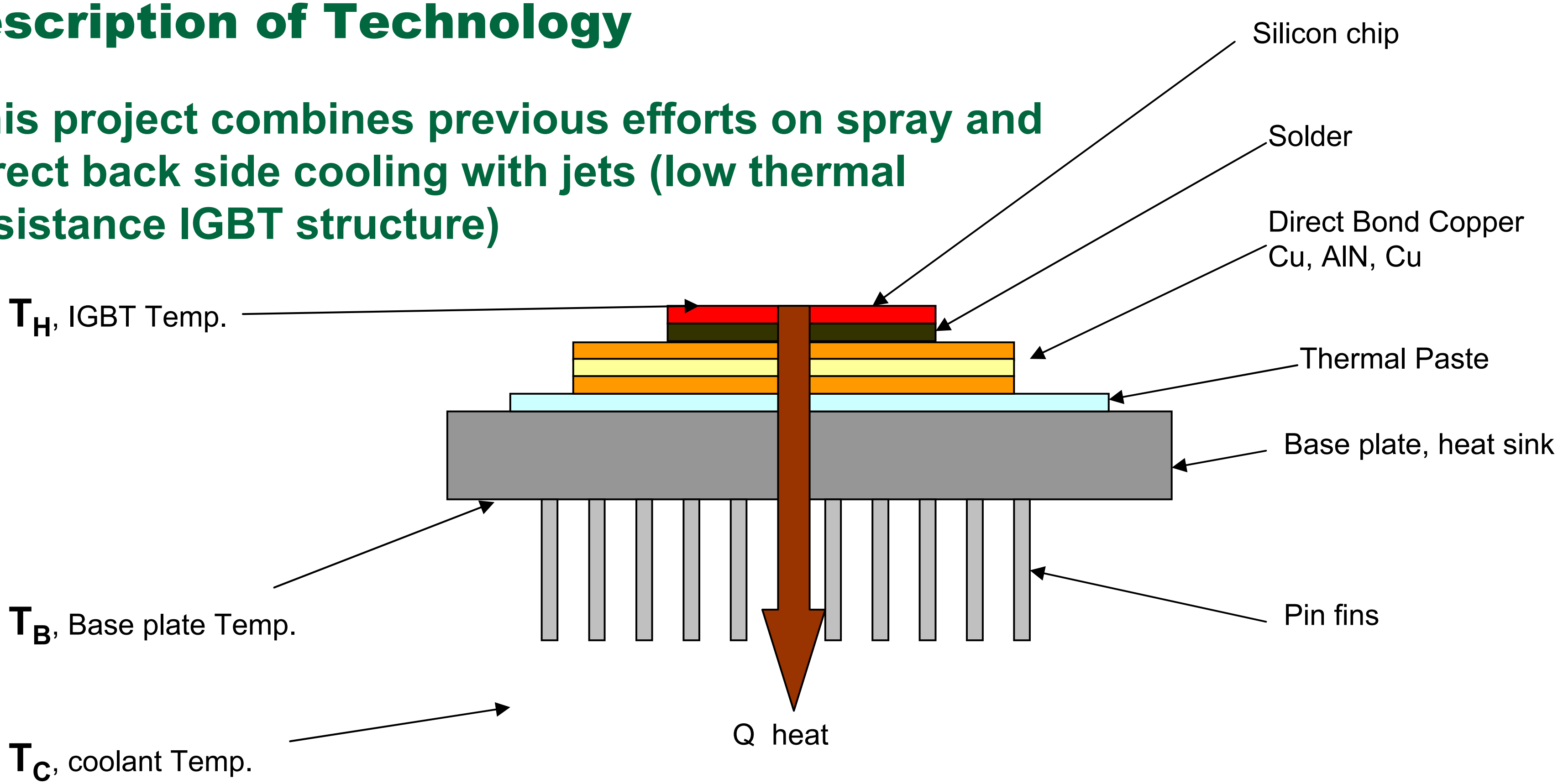
The Problem

- Enable the use of 105^{o}C coolant to reduce the thermal control cost by completely eliminating a separate coolant loop.
- For performance and long term reliability, die temperature needs to be below 125^{o} C with conventional IGBT technology (150^{o} – 175^{o} C with Trench IGBT).
- Current approach of using a separate coolant loop at 70^{o} C is costly relative to the overall FreedomCAR goals [for 2020 cost target of $8/kW for a 55 kW traction system].
- Target for specific power at peak load is > 1.2 kW/kg while for volumetric power density is > 3.5 kW/liter.

Description of Technology

This project combines previous efforts on spray and direct back side cooling with jets (low thermal resistance IGBT structure)



$$Q = h\,A\,(T_B - T_C)$$

$$Q = \frac{(T_H - T_B)}{R_{solder} + R_{DBC} + R_{TIM} + R_B}$$

Description of Technology

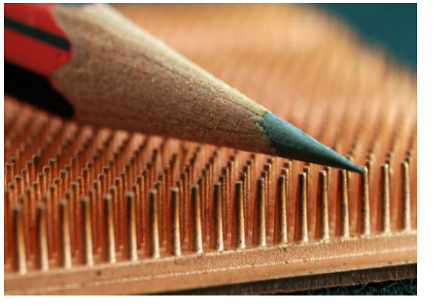
Improve PE device efficiency (ORNL)

Optimize base plate temperature
- PE materials development (working closely with ORNL)
- Reduce thermal resistance

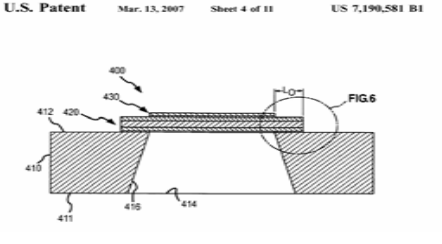
coolant temperature is 105° C

$$Q = h\ A\ (T_B - T_C\ )$$

Increase surface area
- Fin shape optimization
- Double sided cooling
- Surface enhancements
- Thermal Spreading



Enhance heat transfer coefficient
- jet/spray cooling
- self-oscillating jets
- phase change

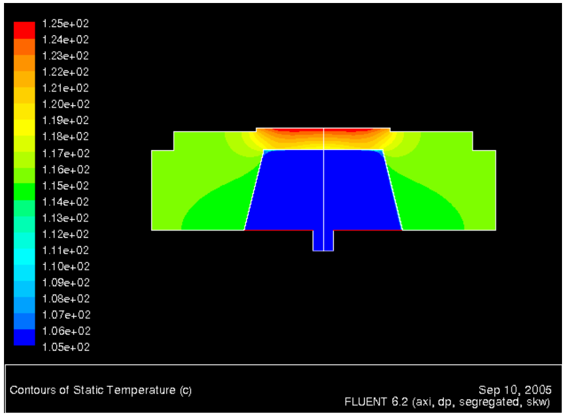


Uniqueness of Project and Impacts

- New approach looks at novel thermal solutions which are integrated with Power Electronics (PE) development by closely working with ORNL PE Tech and industry partners.
- By looking at thermal aspects during PE development, innovative PE could be explored, which have not thought to be practical.
- Efficient thermal control would aid in making PE devices smaller which could drive down the cost.

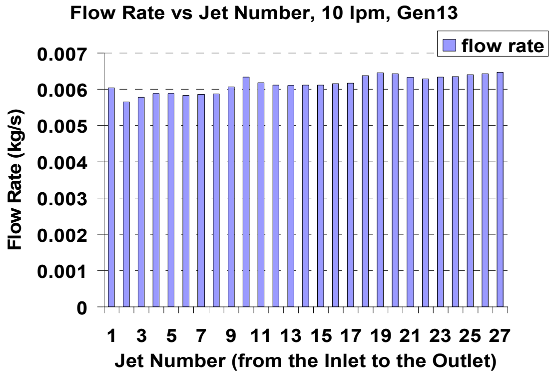
Accomplishments to Date
(for projects funded in prior FYs)

Low Thermal Resistance Power Module and Oscillating Jets



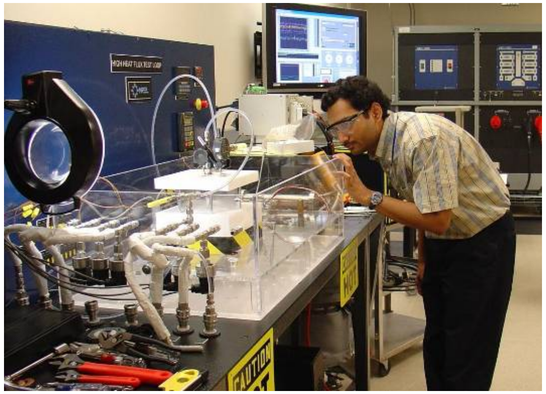
<ins>Status</ins>

- Awarded patent for "Low Thermal Resistance Power Module Assembly"
- Completed testing to show the potential of self-oscillating jets for power electronics cooling



<ins>Benefits</ins>

- Concept enhances heat transfer from power electronic components by allowing forced liquid jets to cool the backside of the electronics
- By transferring heat more effectively than existing methods, the weight and cost of power electronics devices can be drastically reduced
- The velocity variation between the jets is within 8%
- Self-oscillating jets have the potential of further improving heat transfer (about 18%) with no moving parts

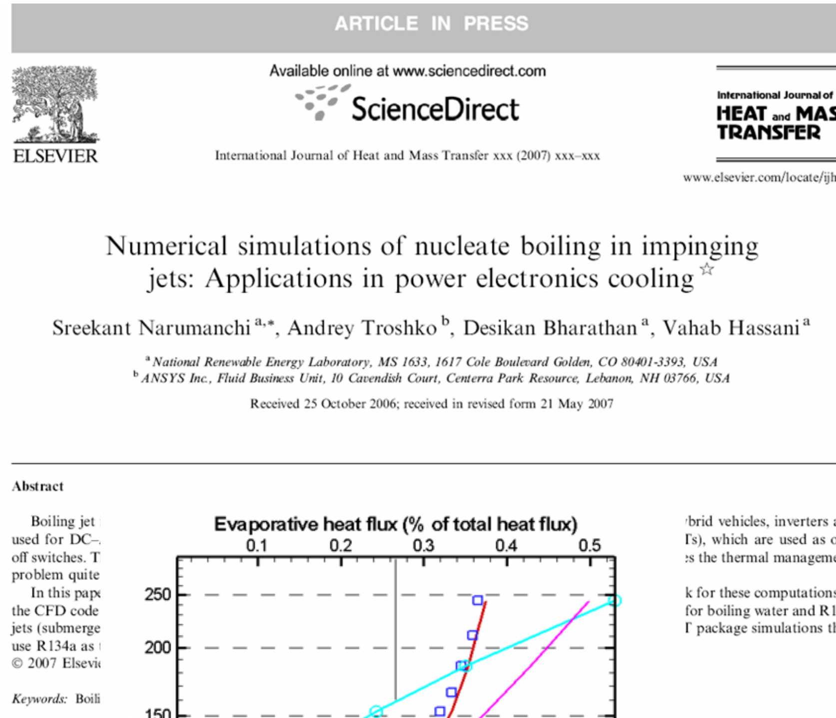


Accomplishments to Date
(for projects funded in prior FYs)

Two-phase Modeling, NREL

<u>Status</u>

- Two phase modeling results published in International Journal of Heat and Mass Transfer
- Validation of NREL modeling with experimental data available in the literature
- Demonstrated conditions for two-phase with R134a that would dissipate 200 W/cm^2 while keeping the die temperature close to 125^o C



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Numerical simulations of nucleate boiling in impinging jets: Applications in power electronics cooling ☆

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Abstract

Boiling jet … ·brid vehicles, inverters are
used for DC–… Ts), which are used as on/
off switches. T… s the thermal management
problem quite…
In this pap… k for these computations is
the CFD code… for boiling water and R113
jets (submerge… T package simulations that
use R134a as…
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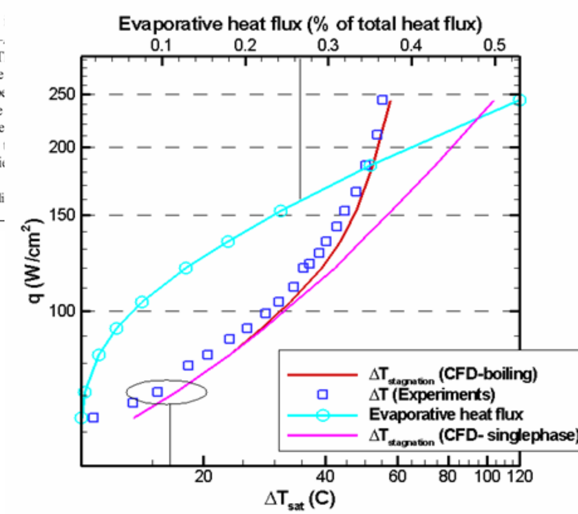
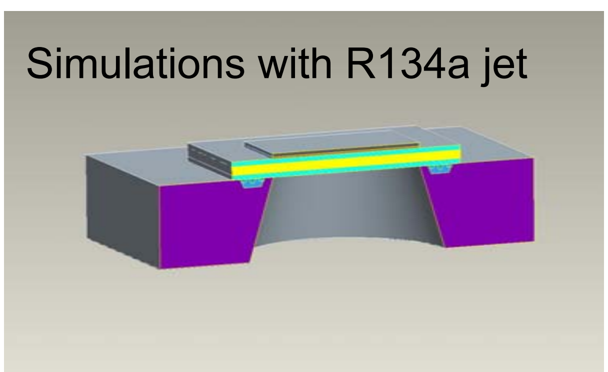
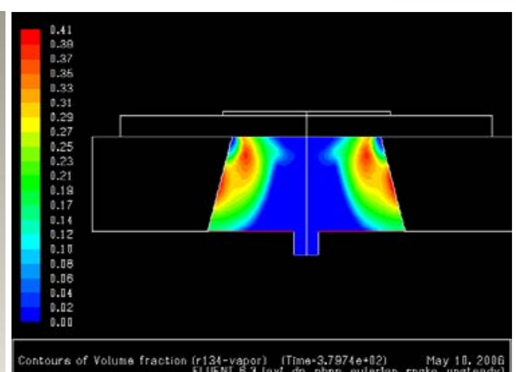
Keywords: Boili…







Accomplishments to Date
(for projects funded in prior FYs)

Two-phase Jet and Spray Cooling tests

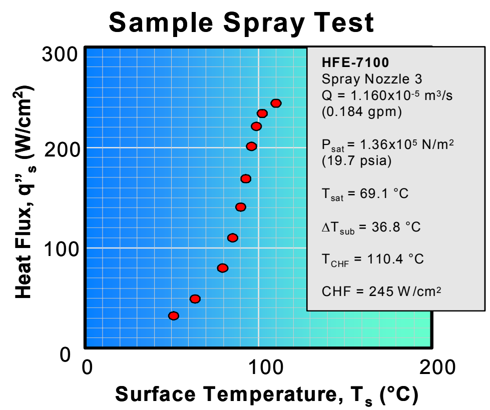
Status

- Mudawar Thermal Systems has constructed the test apparatus for two-phase jet and spray cooling
- Nucleate boiling curves have been established for HFE-7100 using jets and sprays on a 1x1 cm test surface
- Demonstrated conditions with two-phase dielectric coolant that could achieve > 200 W/cm^2 heat flux while maintaining 125^o C chip temperature

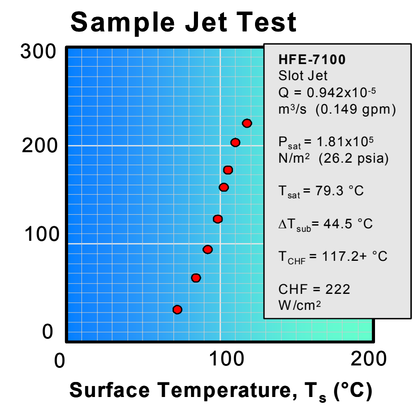
Benefits

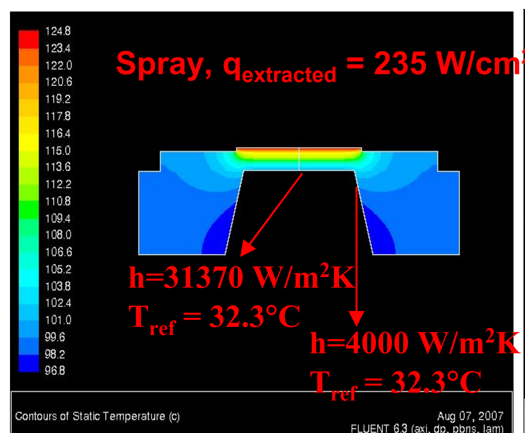
- Two-phase heat transfer provides an alternative means for achieving high heat flux requirements

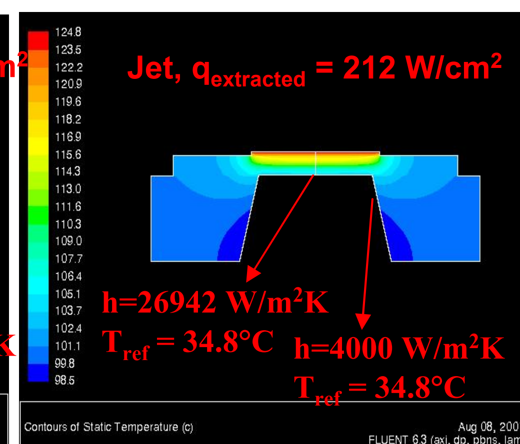
(a)



(b)







Project Objectives for FY08

- **Complete characterization of single and two-phase spray and jets**

  - Perform thermal testing and also validation of thermal models for low thermal resistance IGBT structure design

  - Publish consistent, objective comparison of existing technologies

- **Assess the potential with spray and jet technologies to meet thermal targets using 105^{o}C coolant**

- **Identify additional thermal control parameters to enable system cost, weight, and volume reduction**

  - Surface area enhancement

  - Materials to improve thermal performance, cost and weight

  - Overall system cost reduction

- **Develop optimized/integrated thermal solution**

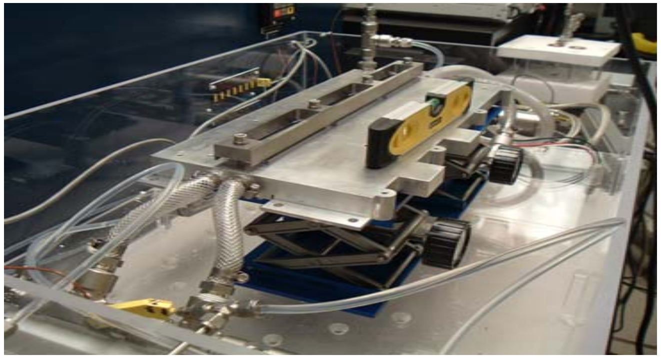
  - Thermal control integrated with PE system

  - Close collaboration with ORNL and industry partners

Technical Approach for FY08

Publish a paper on self-oscillating jets at Semitherm, 3/08

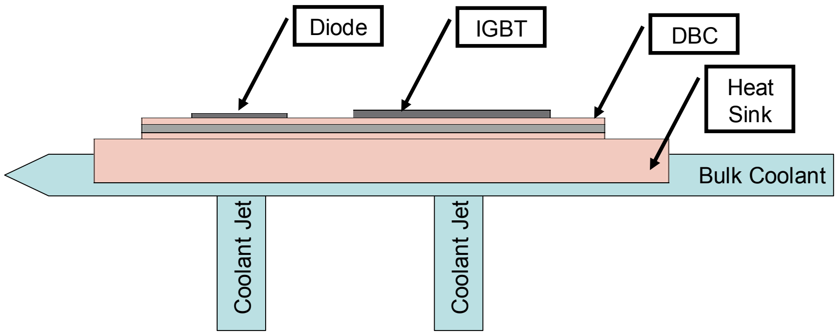
Publish a paper on Two-Phase Experimental and Model Validation at ITherm, 5/08



Complete Thermal testing/validation and submit a conference paper, 9/08

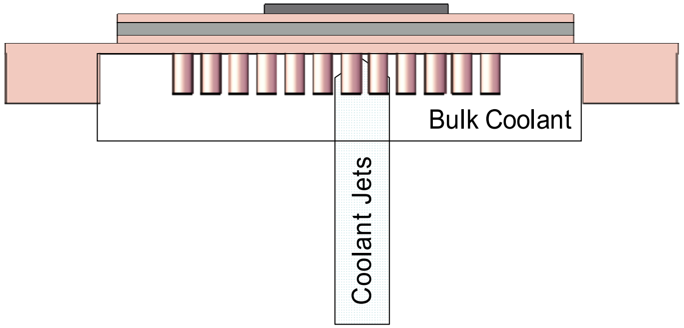
Technical Approach for FY08

1. Maximizing Heat Transfer Coefficient, h



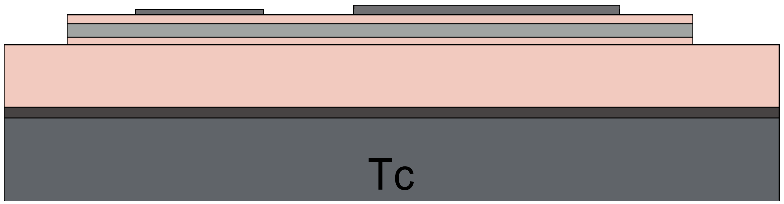
Assessing existing technologies like spray, oscillating jets, direct back side cooling, etc.

2. Enhancing Surface Area, A



Surface area is a key parameter for enhancing heat transfer, enabling volume and cost reduction

3. Optimizing Cold Plate Temperature, T_B

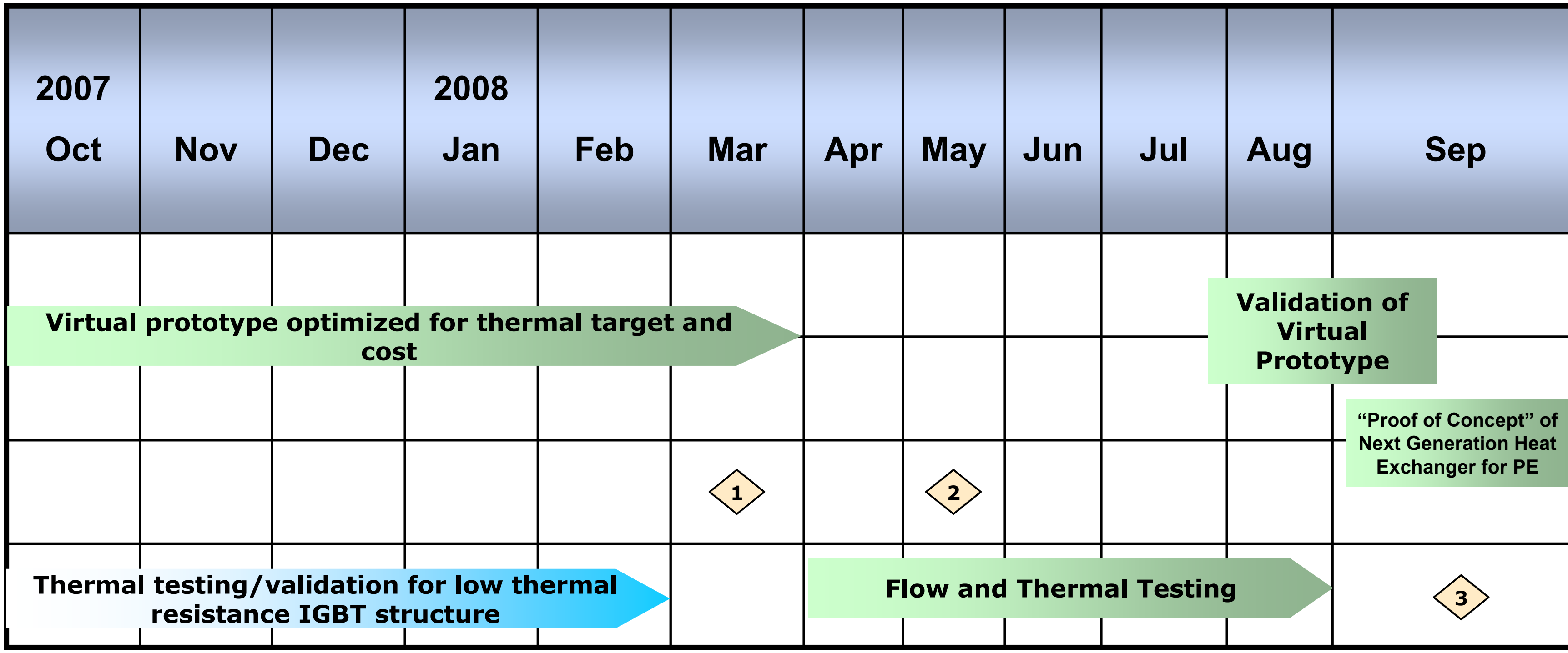


Alternate materials would be explored from the die to the cold plate for cost reduction

4. Concurrent Engineering

Close collaboration with ORNL PE Tech team and industry partners to drive cost reduction

Timeline



- **Publish**
  - ◇1 **Self-oscillating jet paper (Semitherm, co-authored with Bowles Fluidics), 3/08**
  - ◇2 **Two-phase experiments with numerical results (ITherm, co-authored with Mudawar Thermal Systems), 5/08**
  - ◇3 **Submit a conference paper on Low Thermal Resistance IGBT Structure (9/08)**

The Challenges/Barriers *to implement 105°C coolant*

- **Extra cost due to design changes could exceed the cost benefits due to the elimination of a separate coolant loop.**
- **Size of the capacitors could increase.**
- **Long term reliability could decrease for PE, motors and capacitors.**
- **Flux strength of the motors could decrease by about 20 – 30% when the coolant at 105^{o} C is used.**
- **Stator losses could increase by about 30% causing the breakdown of winding insulation.**

Beyond FY08

FY09

- Work with ORNL and industry partners to implement low cost 105°C thermal solution
- Interaction with reliability efforts
  - Provide thermal performance data and design parameters to reliability models

Questions