Deliverable #1: Project Plans & Product Specifications

Team 9 – Phase Change Material Transient Heatsink for Power Semiconductor

Sponsor:
Unison Industries

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1.0 Problem Statement

The objective of this senior design project is to create a heatsink for power semiconductors in aerospace applications. In order to accommodate transient thermal loading conditions encountered in such applications, the heatsink will incorporate a phase change material in order to store thermal energy from the power semiconductors during those periods of the duty cycle in which convective heat transfer rates are low.

2.0 Project Scope

From the sponsor's project description:

"Among the electrical products Unison Industries designs and produces for the jet engine industry are ignition units and power regulators which contain power semiconductors. Thermal management of these is a critical part of the design process, maintaining the devices within their reliable operating limits under varying power dissipation levels and ambient conditions. Operating overloads and thermal transients in the ambient environment can be particularly challenging, often adding size and weight to the system."

From the project description, it can be seen that there is a need for a highly-reliable heat dissipation solution for power semiconductors in jet engine systems. As a result of their application, one can imagine that these semiconductors experience many transient thermal loading conditions, such as startup periods and variable atmospheric conditions. Consequently, in designs that use finned heat sinks for thermal management, there may be situations in which high power dissipation rates couple with low convective heat transfer rates to result in unacceptable temperature increases within the semiconductors.

To supplement the convective heat rejection offered by traditional finned heat sinks, this project aims to create a hybrid heat sink that will thermally couple the fins of such a heat sink to a phase-change material (PCM). The PCM will have a melting temperature within the operating temperature range of the semiconductors, and will thus be able to absorb thermal energy as latent heat. In this manner, thermal energy will be able to leave the semiconductors even during periods of low convective cooling, thus maintaining them at a more desirable temperature. Once convective cooling rates rise, the thermal energy stored in the PCM will be conducted through the fins and rejected to the ambient environment through convection.

It should be noted that this hybrid method of thermal management has already been tested and proven as an improvement to finned heat sinks[1,2,3]. The main challenge in the case of this project comes as a result of the area of application: since this heatsink is intended for aerospace platforms, it is necessary that it achieve its goals without significantly adding to an aircraft's size and weight.

3.0 Project Objectives

The most important objectives for our team to achieve are as follows:

1. Identify preferred phase change material(s) for the heatsink, given that the operating temperature range will be 115 – 125°C.
2. Creation of an analytical model that will simulate the heatsink's performance under various thermal loadings
3. An experimental rig for validation of the analytical model

4.0 Methodology

Based on the objectives outlined in Section 3, our design process is essentially broken down into three phases: background research, modeling, and prototyping/validation. These phases are further outlined below. Numbers contained in square brackets (i.e., **[1]**) are links to the aforementioned objectives.

4.1 Background Research

During this phase, we plan to:

- Conduct a literature search to find relevant modeling and analysis techniques
- Conduct a patent search and discuss our results with FSU's patent attorneys to ensure that our design does not infringe on existing intellectual property
- Identify potential materials for use as PCMs **[1]**

4.2 Modeling

Once we have gained a sufficient knowledge base, we will:

- Determine the equations needed to sufficiently model the thermodynamics of our system
- Determine the design parameters that will control our heatsink's performance
- Create simulations of individual heatsink designs using variations of our design parameters **[2]**

4.3 Experimentation/Verification

Once we are reasonably confident in the fidelity of our simulations, we will:

- Work with either the College of Engineering or Unison to manufacture our heatsink designs **[3]**
- Acquire either a power semiconductor or an equivalent simulator of its thermal loading and integrate it into our heatsink **[3]**

- Install temperature monitoring systems for the power semiconductor, heatsink, and ambient environment **[3]**
- Collect and analyze temperature data to compare designs' performance characteristics to their theoretical capacities
- Use our experimental results to revise our design rules and select an optimal design for manufacturing

5.0 Project Constraints

Time: Our entire team is composed of full-time students who also hold part-time positions. As such, it will be difficult not only to put a sufficient amount of work into our design, but also to coordinate our schedules for tasks that will require the entire team. To assist in alleviating the scheduling issue, we have created a Google Calendar that lists all of our individual obligations, in order that we can anticipate them and schedule tasks around them. Furthermore, we are using a project planning software known as OmniPlan to create Gantt charts that track our project progression and task responsibilities.

Budget: Our project has been allocated $2,000 by Unison, and our design/testing must stay within this limit. As such, we will have to ensure that any purchases we make are necessary to the completion or improvement of our project objectives, and that we make cost-conscious decisions when choosing between design or component alternatives.

6.0 Deliverables

6.1 Work Breakdown Structure

Based on the methodology outlined in Section 4, our project can be broken down according to the following work breakdown structure. Numbers contained in square brackets (i.e., **[4.1]**) are links to the subsections of Section 4. Items in **bold** indicate milestones, and underlined items are tasks identified as critical to project progress. Each task is prefaced with the first name of the team member responsible for its completion. If a name is not given before a task, it is to be undertaken by all team members. Also, to more effectively illustrate the chronological structure of our project, as well as the dependencies between tasks, a Gantt chart has been provided in Appendix A.

- Procurement and Setup for Prototype Testing (Weeks 1-4)
    - Kegan: Set up testing equipment **[4.3]** and get heatsink prototypes manufactured at the College of Engineering's machine shop
    - Daniel: Develop experimental test plan **[4.3]**, revise project plans and product specifications
        - **Project Plans and Product Specifications (1/17)**
    - Joseph: Purchase items needed for manufacturing/testing **[4.3]**, keep track of all expenses, keep website up to date
        - **Updated Website (1/31)**

- Prototype Testing (Weeks 5-8)
    - Kegan/Joseph: Responsible for handling and monitoring equipment (including data acquisition) during testing
    - Daniel: Responsible for setup and breakdown of testing equipment, as well as keeping a log of experimental observations
    - Compare experimental performance of designs to simulated results, revise simulation parameters/design rules **[4.3]** as dictated by experimental results and observations, select optimal design for manufacturing
        - **Midterm Presentation/Design Review I (2/11)**
- Design for Manufacturing (Weeks 9-12)
    - Work with Kevin to develop a manufacturing plan for our selected design **[4.3]** (possibly take a trip to Unison to become more familiar with their manufacturing capabilities)
        - **Midterm Presentation/Design Review II (3/18)**
        - **Operational Manual (3/28)**
- Project Wrap-Up (Weeks 13-16)
    - Create final reports and presentations by compiling previous deliverables and revising their contents based on sponsor/advisor feedback, practice final presentation thoroughly
        - **Design for Manufacturing/Reliability and Economics (4/4)**
        - **Design Review II (Presentation Walk-Through) (4/8)**
        - **Final Presentation/Report/Website (4/17)**

In addition to the tasks listed above, we also have tasks that occur periodically. Specifically, we will meet with Dr. Amin and Dr. Shih for bi-weekly staff meetings, will have phone conferences at least once per month with our industry sponsor (Kevin Walker), and will meet with our faculty advisor (Dr. Taira) at least once per month.

7.0 Product Specifications

In order to ensure that this project meets the customer's needs, we have defined a set of design and performance specifications below.

7.1 Design Specifications

- Semiconductor geometric dimensions (given in Fig.1, used to design heatsink)
- Housing specifications:
    - Low coefficient of thermal expansion (CTE), closely matched to that of PCM
    - High thermal conductivity of both housing and thermal coupling with the outside wall
    - Maintains contact area with power semiconductor during PCM phase change (i.e., must not deflect significantly during phase change to avoid reduction in surface area needed for thermal conduction)
    - Able to damp out vibrations experienced during aircraft operation (to avoid fatigue failure and consequent leaking of PCM)

- PCM specifications:
  - High thermal conductivity
  - High specific heat
  - Low CTE during phase change (in order to minimize volumetric changes that would place stresses on the housing)
  - Melting temperature in range of surface temperatures of power semiconductor in overload conditions (around 115-125°C)

7.2 Performance Specifications

- Able to withstand transient heat conditions (nominal 1-2W, maximum 3-4W)
- Able to absorb heat from power semiconductor baseplate (made of molybdenum)
- Able to dissipate the absorbed heat to the outside wall away from the semiconductor
- Able to operate properly with a temperature range of 115-125°C

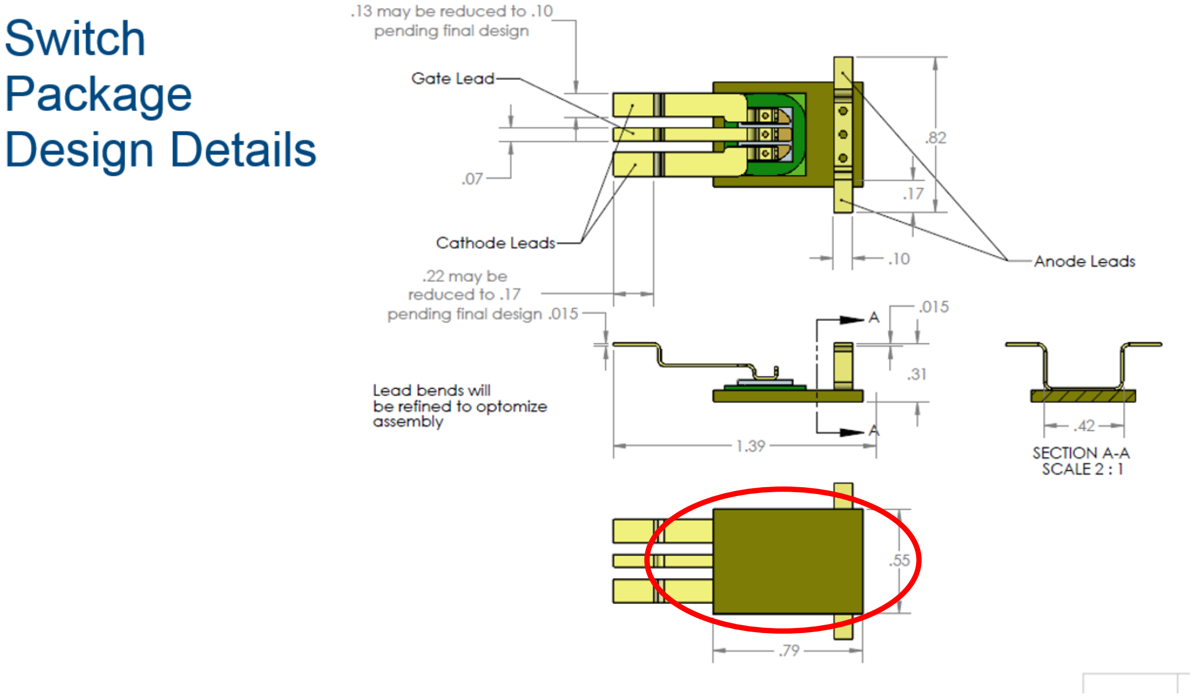

Figure 1. Semiconductor geometry. All dimensions are in inches. Available contact area for thermal coupling with heatsink is circled in red.

8.0 References

[1] Fossett, A. J. et. al., “Avionics Passive Cooling With Microencapsulated Phase Change Materials,” *Transactions of the American Society of Mechanical Engineers*, Vol. 120, 1998, pp. 238-242.
[2] Krishnan, S., Garimella, S. V., and Kang, S. S., “A Novel Hybrid Heat Sink using Phase Change Materials for Transient Thermal Management of Electronics,” *IEEE Transactions on Components and Packaging Technologies*, Vol. 28, 2005, pp. 281-289.
[3] Leland, J. and Recktenwald, G., “Optimization of a Phase Change Heat Sink for Extreme Environments,” PhD thesis, Portland State University, Mechanical Engineering Department.

Appendix A: Spring Semester Gantt Chart