1.0 Name: Firstname Lastname (SJSU ID: #########)

2.0 Project Title:

Development of a porous layer fabrication process for liquid cooling of printed circuit boards

3.0 Background:

Gordon Moore, co-founder of Intel (Santa Clara, California), made a prediction in 1965 that transistor counts in electronics would double every 18 months [1]. This prediction later also holds true for the performance of the processor being doubled and has become a frequently quoted design goal for many research and development institutes in the electronic industry.

With the rapid improvement in performance, electronic device also rapidly generates heat. Moreover, recent generations of electronic tend to shrink in physical size while continuing to have superior computing power than its predecessor. Due to the lack of contacting surface, conventional metal heat sinks struggle to maintain the electronic in operational temperature. Thus, insufficient heat dissipation has become a bottleneck for the advancement in electronic as an overheating component will experience reliability issues such as reduced gain, output power, efficiency, and ultimately failure[2].

A replacement thermal solution must be developed in order to satisfy the growing need of heat removal in electronics. This has led to the revival of fluid cooling with microchannel. Many have credited the work of Tuckerman and Pease in 1981 as the first major publication on microchannel liquid cooling of electronics [2]–[4]. Although the technique was not well-received due to the immaturity of microfluidic manufacturing at the time, the recently growth of popularity with microfluidics and microelectromechanical system (MEMS) have demonstrated potential for microchannels cooling for electronics.

Currently, the development of microchannel cooling is healthily growing. Kandlikar et al. reviewed the status of the technology in 2013. They commented that in order for the cooling of single phase liquid in microchannel to dissipate a heat flux of 1 kW/cm^2 with an average temperature difference of 20 °C from inlet to outlet; the device must has at least a heat transfer coefficient of 500 $kW/m^2 \cdot °C$. They suggested that heat enhancement elements inside of the microchannels such as pins and porous media are the next steps in microchannel cooling [5]. In addition, there are experimental results that disagree with the classical governing equations and credit the discrepancy to the friction or the roughness of the wall [6], [7]. Vijayalakshmi et al. commented that compressibility of the fluid is a contribution for this discrepancy [8].The discrepancy demands for analytic investigations as many fluid mechanic and heat transfer phenomena in micro or nano scale do not follow conventional laws and thus correlated by fits from experimental results [9]. This increases an extra step in the design process as it is necessary to compare the proposed correlations from articles to the classical governing equations [10], [11].

With the escalating need of heat removal, the concept of porous media has been explored. While simply inserting metal foam into a microchannel has been studied [12], [13], there is the need to develop a compact, closed loop micro-cooling system for small electronics such as mobile smart phone. This project seeks to complete the following objectives in order to fill the need.

4.0 Objectives:

1. The main objective of this project is to develop a fabrication process for a PCB-compatible micro-porous layer for microscale heat removal by convection.
2. A supporting objective of this project is to examine the effect of layer characteristics (e.g., width/height aspect ratio porosity, tortuosity, thermal conductivity) on heat transfer rate.
3. Another supporting objective is to evaluate the heat transfer effectiveness of the fabricated porous layer compared to published results using microchannel cooling.

5.0 Methodology:

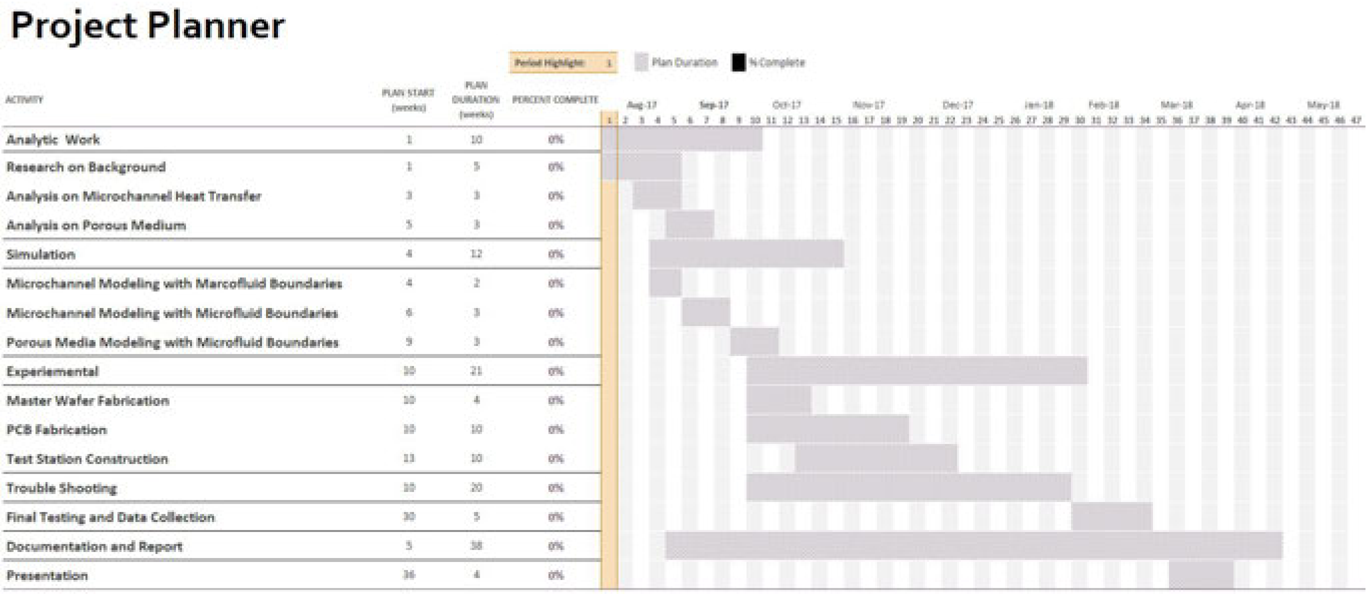
1. Review published literature and identify existing thermal solutions used in electronics:
    a. Conduction by heat sink
    b. Convection by forced induced air by fan
    c. Conjugated convection by liquid cooling
2. Analytical:
    a. Determine the pressure drop across a preliminary microchannel using macroscale Navier-Stokes equation:
        i. $$\rho\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + u\frac{\partial u}{\partial z} = \rho g_x + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \qquad \text{(a)}$$
        ii. Where **ρ** is the density, u is the downstream velocity, g is the gravity constant, p is the pressure, μ is the dynamic viscosity
    b. Determine the heat transfer coefficient across the microchannel using macroscale energy balance
        i. $$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 \qquad \text{(b)}$$
        ii. Where T is the temperature, α is the thermal diffusivity, ν is the dynamic viscosity, and the c_p is the heat capacity of the fluid
    c. Determine the pressure drop across the microchannel using Navier-Stokes equation corrected for porous media based on [10]:
        i. $$-\frac{1}{q}\frac{\partial p}{\partial x} = \frac{\mu(1-\varepsilon)^2}{\varepsilon^2}2\chi^2 A_{vd}^2 + \frac{q\rho(1-\varepsilon)}{\varepsilon^2}0.0968\chi^3 A_{vd} \qquad \text{(c)}$$
        ii. Where q is the superficial velocity, ε is the porosity, χ is the tortuosity, A_{vd} is the specific dynamic surface
    d. Determine the heat transfer coefficient across the microchannel using energy balance equation corrected for porous media based on [11]:
        i. $$\rho c_p u\frac{\partial T_f}{\partial x} = k_{f,eff}\frac{\partial^2 T_f}{\partial y^2} + h_{sf}a_{sf}(T_s - T_f) + S_f \qquad \text{(d)}$$
        ii. Where T_s is the temperature of the solid, T_f is the temperature of the fluid, $k_{f,eff}$ is the effective thermal conductivity of the fluid, h_{sf} is the fluid-solid heat transfer coefficient, S_f is the internal heat generation of the fluid, and a_{sf} is the specific surface area

3. Simulation:
    a. Construct a simulation of a steady state microchannel with uniform heat flux along one surface and simulate the heat transfer with water flow through the microchannel assuming no temperature and velocity slip at boundary.
        i. Produce a plot of pressure drop and heat transfer coefficient as a function of fluid flow rate.
    b. Construct a simulation of a steady state microchannel with uniform heat flux along one surface and simulate the heat transfer with water flow through the microchannel using the corrected boundary based on equation (c) & (d).
        i. Produce a plot of pressure drop and heat transfer coefficient plot as a function of fluid flow rate.
    c. Construct the proposed design of microchannel with porous media and simulate the heat transfer with water using corrected boundary based on equation (c) & (d).
        i. Produce a plot of pressure drop and heat transfer coefficient plot as a function of fluid flow rate.
4. Experimental:
    a. Fabrication of the printed circuit board with the follow layers:
        i. Layout component consist of FR4 and copper
        ii. Layout inner layer: copper
        iii. Internal microfluidic porous heat sink: consist of polydimethylsiloxane (PDMS) for substrate and aluminum for metal foam
        iv. A second layout side consist of FR4 and copper
        v. A final layout layer of copper
        vi. In the exception of the aluminum foam that will be fabricated by electroplating in SJSU, raw materials such as FR4, copper, and PDMS will be purchased from vendors. The final assembly will be done in SJSU.
    b. A master wafer with the etching pattern of PDMS will be fabricated in SJSU by soft lithography.
    c. Design and fabricate the testing apparatus and data acquisition (DAQ) hardware:
        i. Sensor for
            1. Temperature: Type K thermocouple at in the inlet and outlet of the cooling system
            2. Pressure: Pressure transducer at the inlet and outlet of the cooling system
            3. Flow rate: Rotameter in the range of milliliters per minute; (e.g., FL3692G from Omega Engineering (Stamford, CT)
            4. Temperature and pressure will be logged by a DAQ card, while the flow rate will be logged manually
        ii. Heating element: A polyimide film heater with power intensity of 150 W/m^2 will be attached to the top of the PCB by adhesive. e.g., KH-205/(100)-P from Omega Engineering
        iii. Assembly for the cooling cycle: micropump (miniature rotary pump: e.g., M400 model by TCS Micropumps (Faversham, UK), reservoir, cooling system, and condenser

6.0 Deliverables:

1. A written protocol that includes the materials, hardwares, and process, necessary to fabricate the proposed liquid cooling system.
2. Fabricated porous-layer specimens, at least two replicates at two different thicknesses and two different porosities (i.e., planned minimum of eight test specimens).
3. A functioning test station that applies a prescribed uniform heat flux to a printed circuit board and measures temperature distribution, pressure drop, and flow rate across the porous cooling layer.
4. A plot of analytic solution of pressure drop and heat transfer coefficient as a function of fluid flow rate through the porous layer.
5. A simulation plot of pressure drop and heat transfer coefficient as a function of fluid flow rate through the porous layer.
6. A plot of experimental data showing pressure drop and temperature difference as a function of fluid flow rate through the porous layer. Furthermore, the experimental result will be compared to published results.

7.0 Timeline:



Project Planner

ACTIVITY	PLAN START (weeks)	PLAN DURATION (weeks)	PERCENT COMPLETE
Analytic Work	1	10	0%
Research on Background	1	5	0%
Analysis on Microchannel Heat Transfer	3	3	0%
Analysis on Porous Medium	5	3	0%
Simulation	4	12	0%
Microchannel Modeling with Marcofluid Boundaries	4	2	0%
Microchannel Modeling with Microfluid Boundaries	6	3	0%
Porous Media Modeling with Microfluid Boundaries	9	3	0%
Experiemental	10	21	0%
Master Wafer Fabrication	10	4	0%
PCB Fabrication	10	10	0%
Test Station Construction	13	10	0%
Trouble Shooting	10	20	0%
Final Testing and Data Collection	30	5	0%
Documentation and Report	5	38	0%
Presentation	36	4	0%

8.0 References:

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