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Report for 2011 URCO Funded Experiment: Development of Optimal Bubble-Seeding Microheaters to Study Nucleate Boiling Heat Transfer in Microgravity

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Abstract

Nucleate Boiling is a known means of efficient heat transfer, enabling high levels of heat flux. The potential application of this mode of boiling to electronics cooling motivates its study both in terrestrial systems and in microgravity. This work describes a study of nucleate boiling on thin wires of varying geometries in microgravity, and the function and testing of a microelectronics cooling system utilizing nucleate boiling. Conditions were found for the onset of nucleate boiling and for burnout of the wires. Testing of the current design of the cooling system is ongoing, and the current results and design are discussed.

Introduction

Nucleate boiling as a means of heat transfer is known to be very efficient. For this purpose, much effort has been put forth to further the understanding of the forces that drive this mode of heat transfer, and to apply it to cooling systems. Such research is ongoing both in terrestrial environments and in microgravity. The development of these nucleate-boiling-based cooling systems would enable development of more powerful microelectronics systems, and such systems would be better able to operate in space, where the environment prohibits heat transfer by air conduction and buoyant convection. In 2010, the USU Get Away Special (GAS) Team's Follow-Up Nucleate Boiling On-Flight Experiment (FUNBOE) studied thin wire nucleate boiling, examining the effects of wire surface geometry and power levels on pool boiling in microgravity. This work is part of a follow-up experiment by the same team – FUNBOE 2.0 – that was performed in June of this year. In this experiment, the development of such a nucleate boiling cooling system is approached using microheater arrays printed on silicon chips, cooling a central heater, and finding the ideal parameters to operate the system.

Experiment Design and Procedure

On June 10, 2011, five GAS students performed the FUNBOE 2.0 experiment aboard a microgravity aircraft. FUNBOE 2.0 was designed to study the characteristics of boiling in water on two platinum wire geometries: a single wire and a three-wire twist. The microheater arrays were made using standard photolithography to deposit a thin film of platinum on a silicon wafer. Three sizes of microheaters were made – 10 μm x 30 μm, 10 μm x 50 μm, and 10 μm x 70 μm – which were arranged in three configurations: a single microheater, a 4x4 grid, and a 7x7 grid (Figure 1). The purpose of the single microheater was to provide an understanding of how

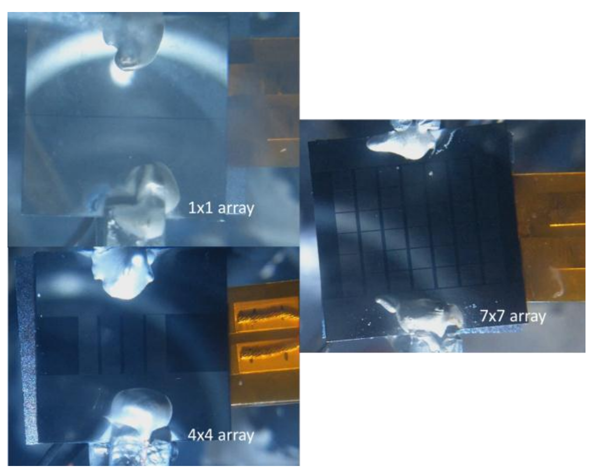

Figure 1 - Microheater array configurations

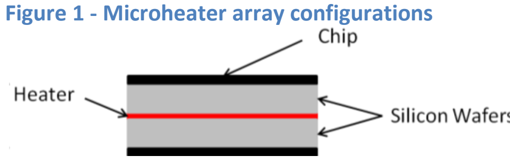

Figure 2 - Microheater assembly with "sandwich" heater

each heater in an array works individually, while the purpose of the grid arrays was to determine the relative effectiveness of each in operation. A polyimide heater was placed between two chips of the same size and configuration during the experiment (Figure 2). The chip assembly was powered by a pulse signal created by a microcontroller and amplified by a stereo receiver. One of each heating element was powered simultaneously on the flight, and elements were switched between each microgravity parabola. Data were collected by a National Instrument CompactRIO Data Acquisition system.

Use of URCO Funds

The nature of the microgravity flight requires that power is provided to multiple heating elements simultaneously. Two existing power supplies were used to power the wires, while a third was purchased with URCO funds to power the polyimide heater between the chips. The platinum wires and polyimide heaters used in the experiment were purchased with URCO funds, the polyimide heaters replacing the microheater arrays in funding due to the high cost of the microheaters. Additionally, time did not allow for the full development and integration of an op-amp circuit to amplify the power signal to the microheaters, so for the flight, a suitable replacement was found in an off-the-shelf stereo receiver with built-in amplifying circuitry.

Results

Flight data collected during FUNBOE 2.0 have been shown to agree with the data collected from FUNBOE, and previously unobserved phenomena were observed during the experiment. One such phenomenon was the onset of nucleate boiling for the three-wire twist, observed at a heat flux value of 512 kW/m^2, which falls within the range determined by the data from FUNBOE. Additionally, burnout of the single wire was observed at a critical heat flux of 51.4 MW/m^2.

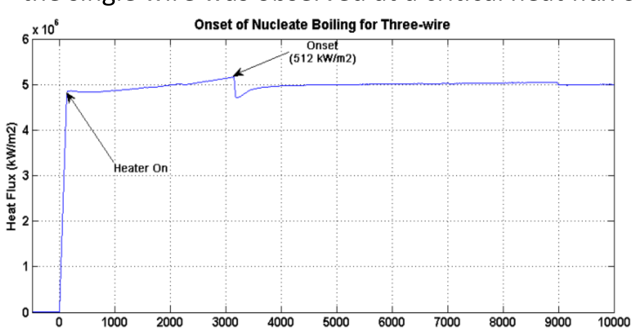

Figure 3 – Heat flux during onset for three-wire twist

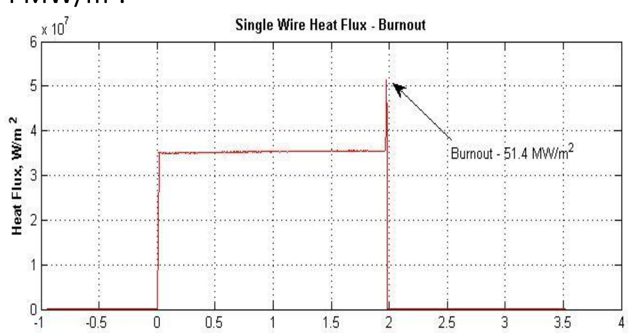

Figure 4 – Heat flux during burnout of single wire

Due to time constraints before the flight, the microheater arrays were not fully optimized, and did not perform as expected on the flight. Post-flight analysis of the arrays is in progress to identify reasons for the lack of boiling. Microscope analysis has revealed that the microheaters were not fabricated with the correct dimensions, and that the platinum layer is more resistive than anticipated, likely due to impurities. The relatively large feature size of the heaters also makes bubble nucleation more difficult. Current ground tests of the arrays show that they have the capacity to boil, though at higher power inputs than were expected. These findings are being used to develop a second generation of microheaters. The processes used to make the make the arrays will be assessed for accuracy, and power

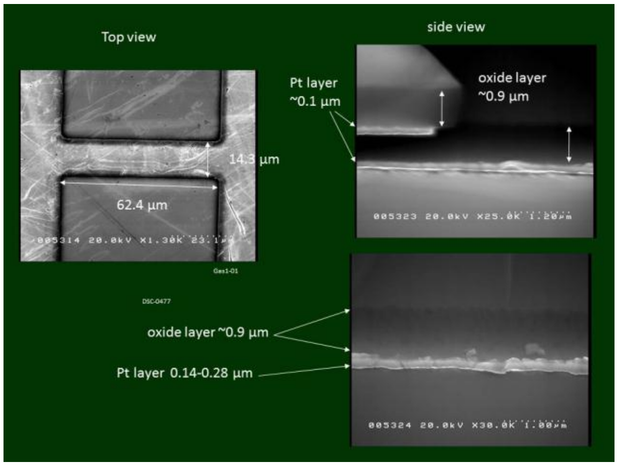

Figure 5 - Electron microscope image of microheater dimensions

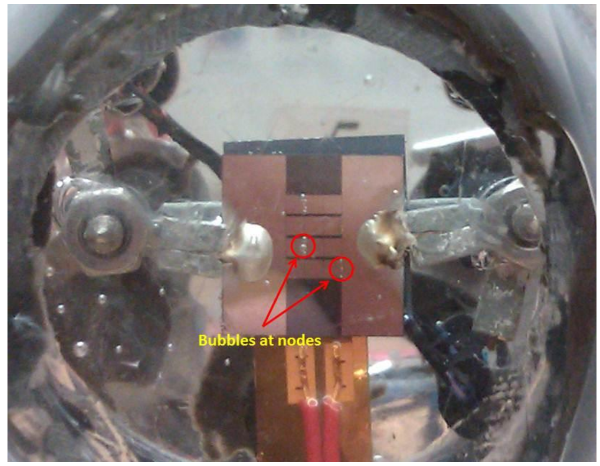

Figure 6 - Boiling on microheater during post-flight test

inputs will be calibrated according to the actual material resistivity. Follow-up experiments aim to see the microheater arrays perform their function as cooling devices and test their efficiency.

Presentation

In April of this year, I presented a poster on the status of this project at the annual Student Showcase. This academic year, I will create a new presentation with new information from the analysis of this experiment. These results will be presented at the April 2012 Student Showcase, the 2012 Posters on the Hill in Salt Lake City, and to the USU AIAA branch.

Impact

The URCO program has enabled me to participate in an experiment and collect data meaningful to the scientific community. Because of my project funded through URCO, I have gained experience in technical writing, electronics design, experiment development, and formal presentations. I have had opportunity to brainstorm and troubleshoot problems. The teamwork skills and memories I have gained will help me throughout my career as an engineer.