NEBRASKA CENTER FOR ENERGY SCIENCES RESEARCH

Flow Boiling with Femtosecond Laser Processed Surfaces and Dielectric Working Fluid

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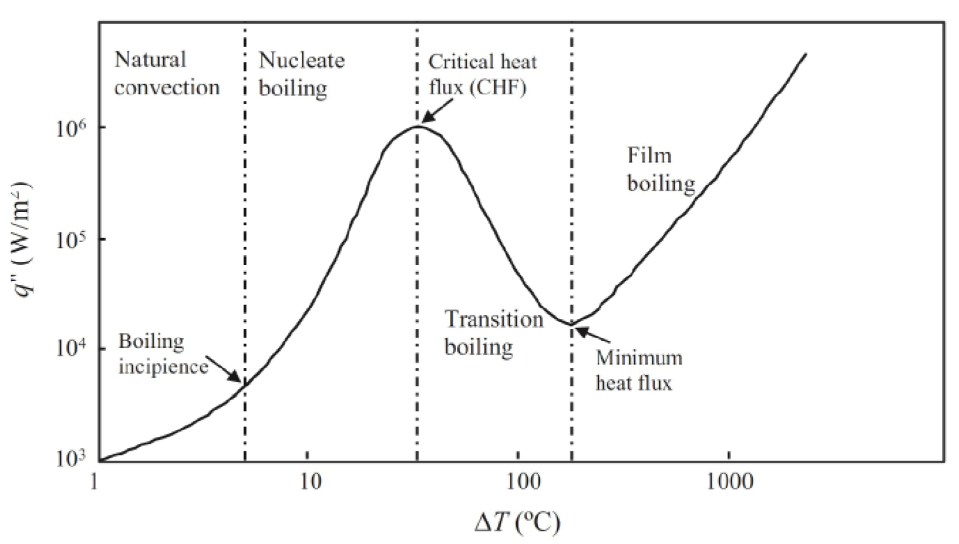
FLOW BOILING

Flow boiling is the boiling of a liquid on the bottom heated surface of a channel while the liquid flows through the channel.

Flow boiling data is often interpreted by plotting heat flux (q'') versus superheat (ΔT), and the resulting figure is referred to as a boiling curve. These curves have four primary areas of interest:

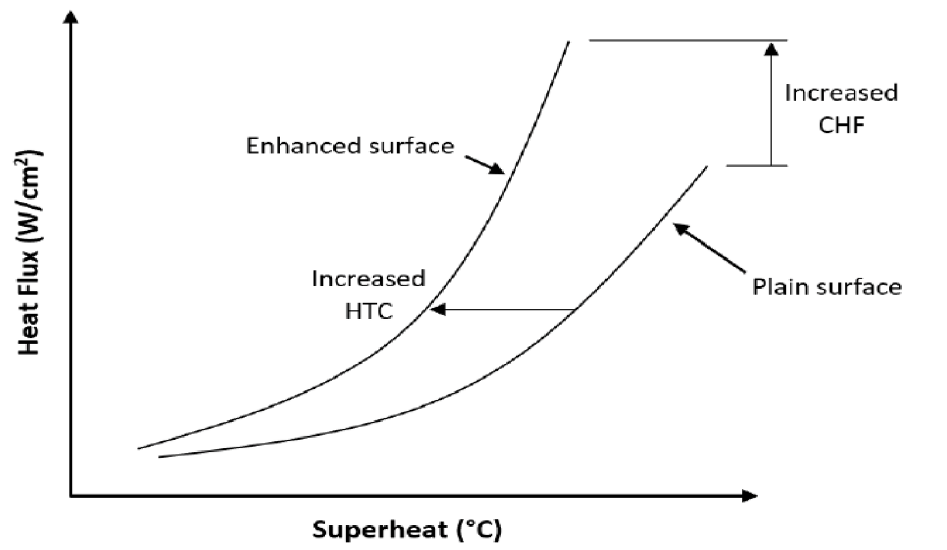
1. Natural Convection Boiling
2. Nucleate boiling
3. Transition boiling
4. Film boiling



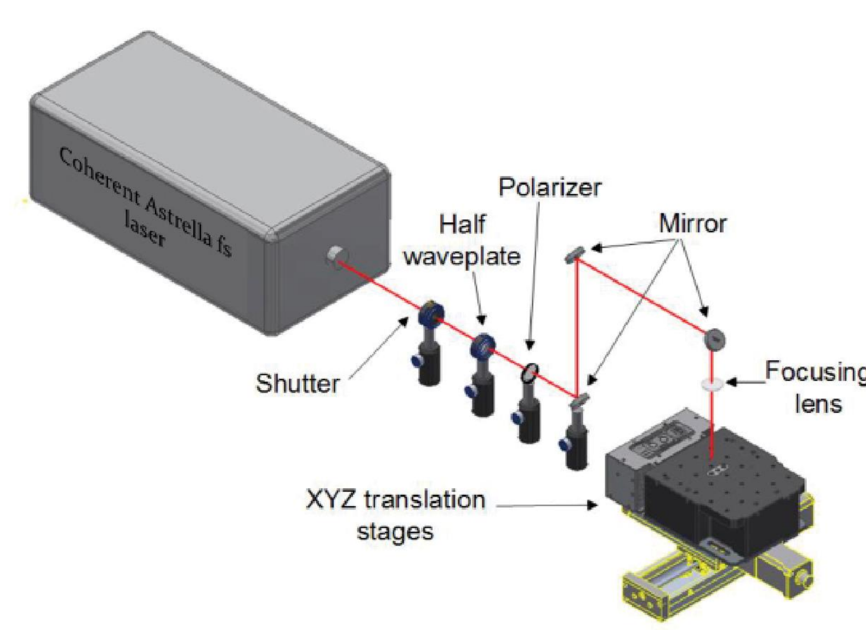
Leong, K.C. et al. (2017). *A critical review of pool and flow boiling heat transfer of dielectric fluids*

Flow boiling is a commonly utilized method of cooling or energy transfer, especially for energy production applications. For example, boiling water nuclear reactors use flow boiling as a method for both cooling and energy conversion. They remove heat from the reactor core and produce steam that is used to generate power.

With these applications in mind, the goal of our studies is to optimize the heat transfer performance between the heated surface and the boiling fluid within the nucleate boiling regime.



FLSP



Femtosecond laser surface processing (FLSP) is a method of using a femtosecond laser to modify the characteristics of a material's surface.

This process creates mound-like microscale features with a nanoparticle layer deposited on top of it.

The laser parameters can be adjusted to alter the characteristics of the processed surface. The primary parameters of interest are pulse count and fluence (the energy output per unit area).

For example, the SEM images shown at different magnifications, Figure 1 and 2, are at the same pulse count, but Figure 2 was processed at higher fluence, which is measured in J/cm².

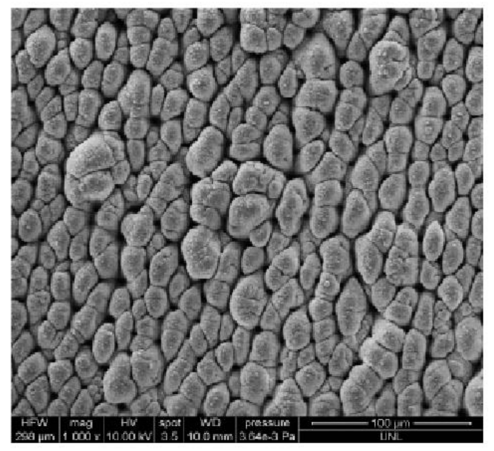


Figure 1

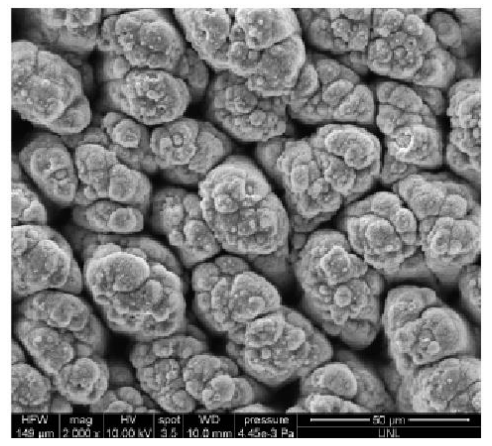
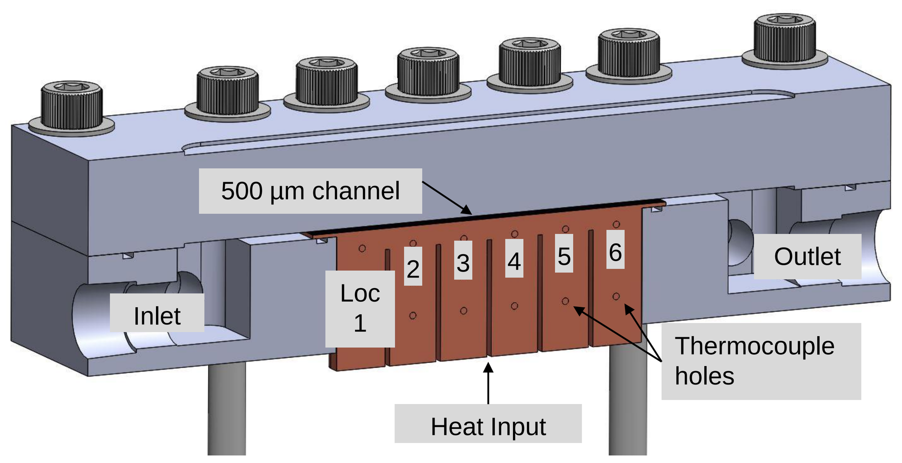


Figure 2

Our studies focus on using this processing technique to enhance flow boiling heat transfer by increasing the critical heat flux (CHF) and/or the heat transfer coefficients (HTC), where the critical heat flux is the maximum possible heat flux before film boiling occurs, and heat transfer coefficient is just the quotient of heat flux over superheat.

Currently, there are various methods that achieve heat transfer enhancement using surface modification, but many of these methods are not permanent or scalable.

FLSP provides a method for creating both permanent and scalable surface features, giving it greater applicability to real world scenarios.



Test Section of Flow Boiling Experimental Setup

DIELECTRIC FLUID

"Dielectric fluids are complex chemical mixtures containing hundreds of primarily semi-volatile, organic compounds. They are designed to be stable, chemically inert, and have good thermal and dielectric properties."

U.S. Department of Commerce, et al. (2019). *Dielectric Fluid Spills (non-PCB fluids)*

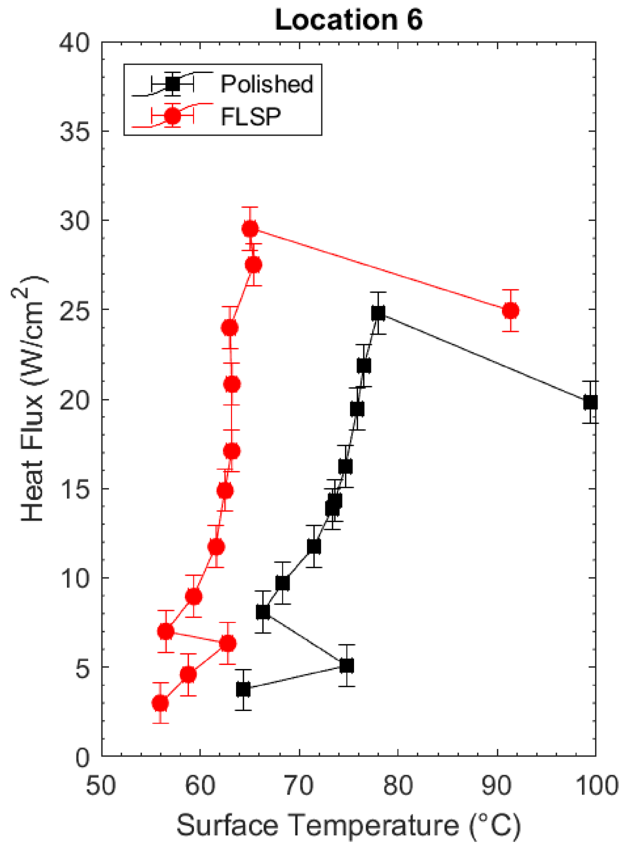
A dielectric fluid is used in this project as it has high dielectric strength, meaning that it acts as an electrical insulator. This makes it ideal for electrical component thermal management, an application in which water would not work. Drawbacks to using dielectrics include a low CHF and a large temperature overshoot before the onset of nucleate boiling.

This project focuses on PF-5060, a 3M fluorinated dielectric fluid. It is used primarily because it is liquid at room temperature and has very similar properties to FC-72, which is used heavily in industry.

RESULTS

We decided to study the effects of FLSP on aluminum surfaces using PF-5060, a dielectric, as the working fluid in a flow boiling mini channel. Dielectrics are commonly used with aluminum instead of water as the aluminum reacts with water to form a Boehmite film. Boehmite can negatively affect the heat transfer of aluminum. This study is relevant as there are many applications of flow boiling in energy production and electronics cooling.

The data presented to the right is the boiling curve for an FLSP surface compared to a polished(baseline) aluminum sample at a flow rate of 60 mL/min. The observed enhancement from the FLSP surface is attributed to increases in surface area, dynamic activation of potential nucleation sites, and increases in the overall nucleation site density created during the laser processing.



The FLSP surface has a higher max heat flux of 31.4 W/cm² at 64.7 °C compared to the polished surface's 26.5 W/cm² at 77.7 °C. This is a 18.5% increase in max heat flux, while also maintaining a lower surface temperature.

The graph also shows the temperature overshoot, or the temperature just before nucleate boiling occurs. The FLSP surface hits the overshoot at 62.7 °C, while the polished aluminum hits the overshoot at 74.7 °C. This shows that FLSP also has a reduction in temperature overshoot, which can increase safety if the temperature overshoot hits dangerously high temperatures.

ACKNOWLEDGMENTS

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