NEBRASKA CENTER FOR ENERGY SCIENCES RESEARCH

Pool Boiling with a Dielectric Fluid and Femtosecond Laser Surface Processed Silicon for Heat Transfer Enhancement

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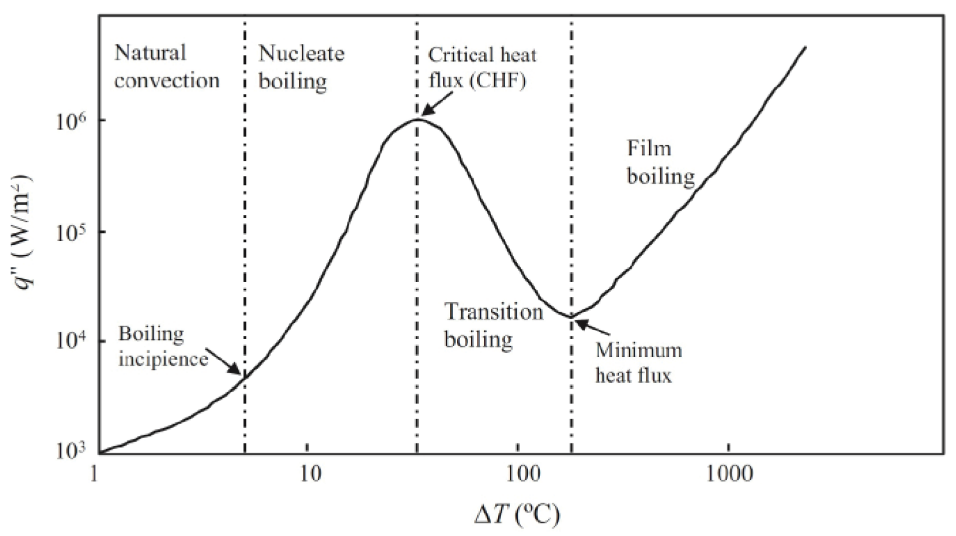
POOL BOILING

Pool boiling is the process of moving energy from a surface to a liquid through natural convection causing a phase change in a fluid bath.

Pool 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:

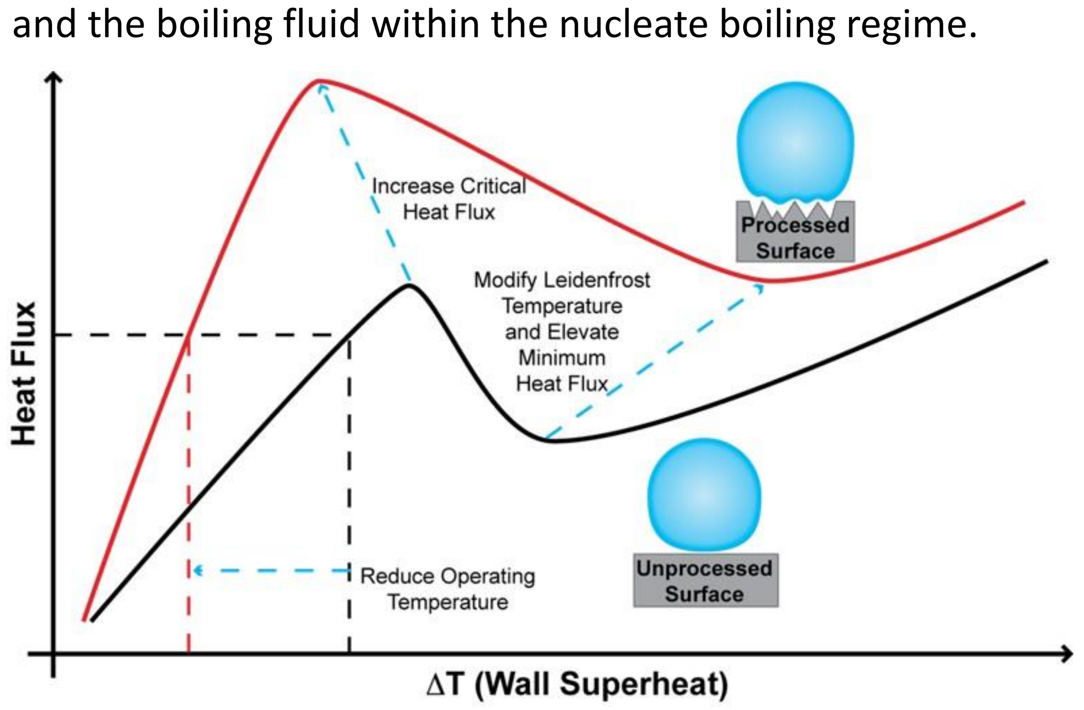
1. Natural Convection
2. Nucleate boiling
3. Transition boiling
4. Film boiling



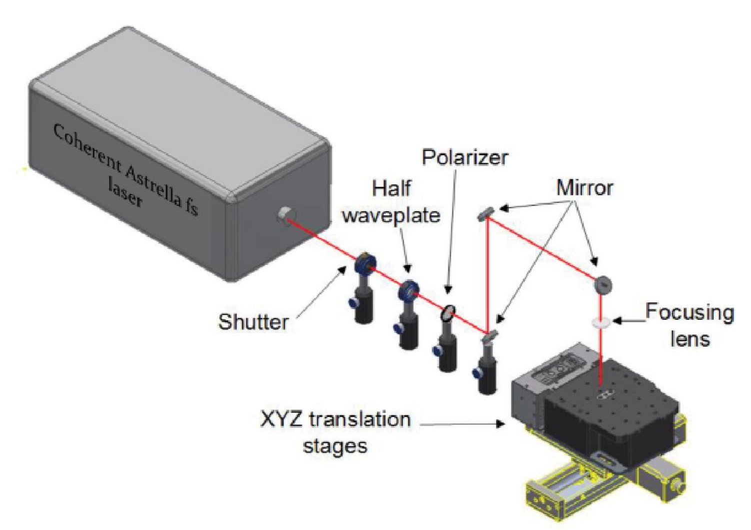
Leong, K.C. et al. (2017). *A critical review of pool and flow boiling heat transfer of dielectric fluids*

Pool boiling is most commonly utilized in immersion cooling, usually for the cooling of electronic components. As the technology industry moves to more powerful and compact components, the cooling of these components becomes more challenging and important.

With this application in mind, our studies aim 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/cm^2.

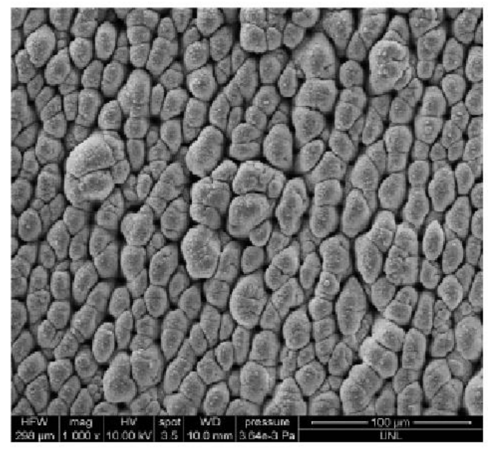


Figure 1

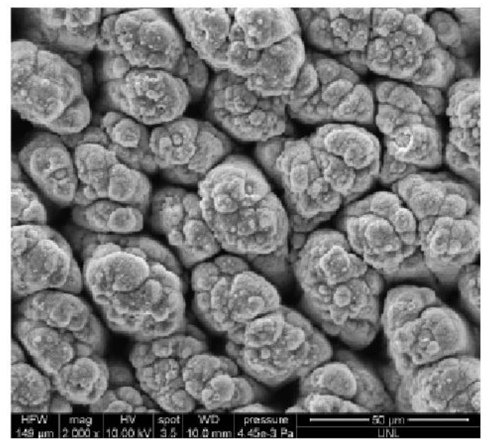


Figure 2

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, various methods 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.

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)*

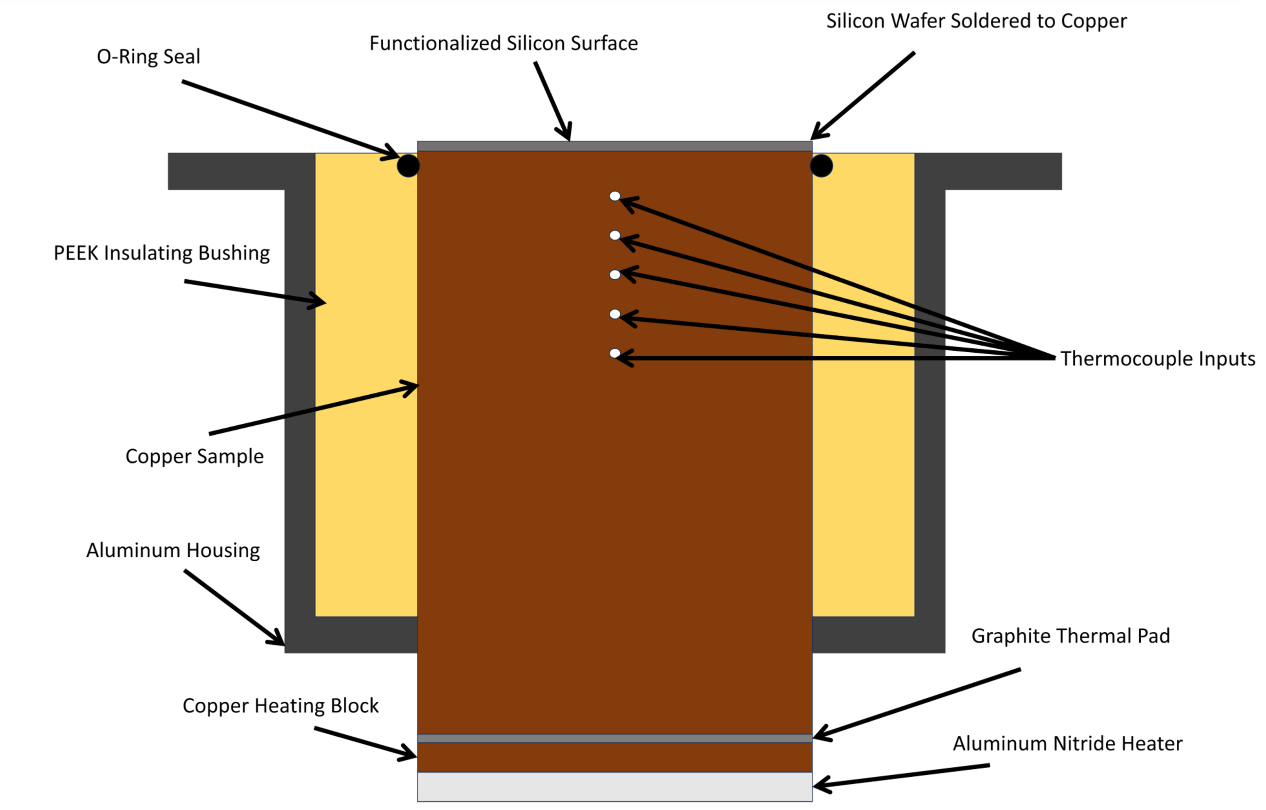
A dielectric fluid is used in this project as it has high dielectric strength, meaning that it acts as an electrical insulator. This makes it ideal for electrical component thermal management, an application in which water would not work. Drawbacks to using dielectrics include a low CHF and a large temperature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

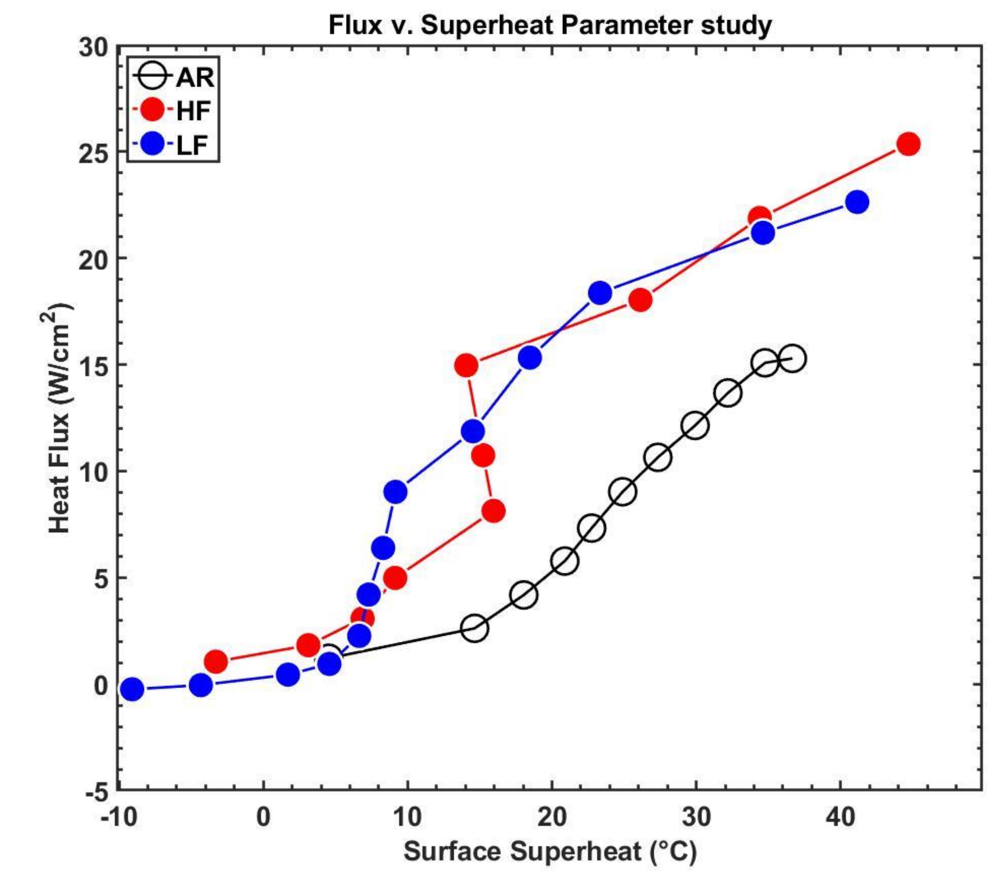
This project focuses on PF-5060, a 3M fluorinated dielectric fluid. It is used primarily because it is liquid at room temperature and has very similar properties to FC-72, which is used heavily in industry.

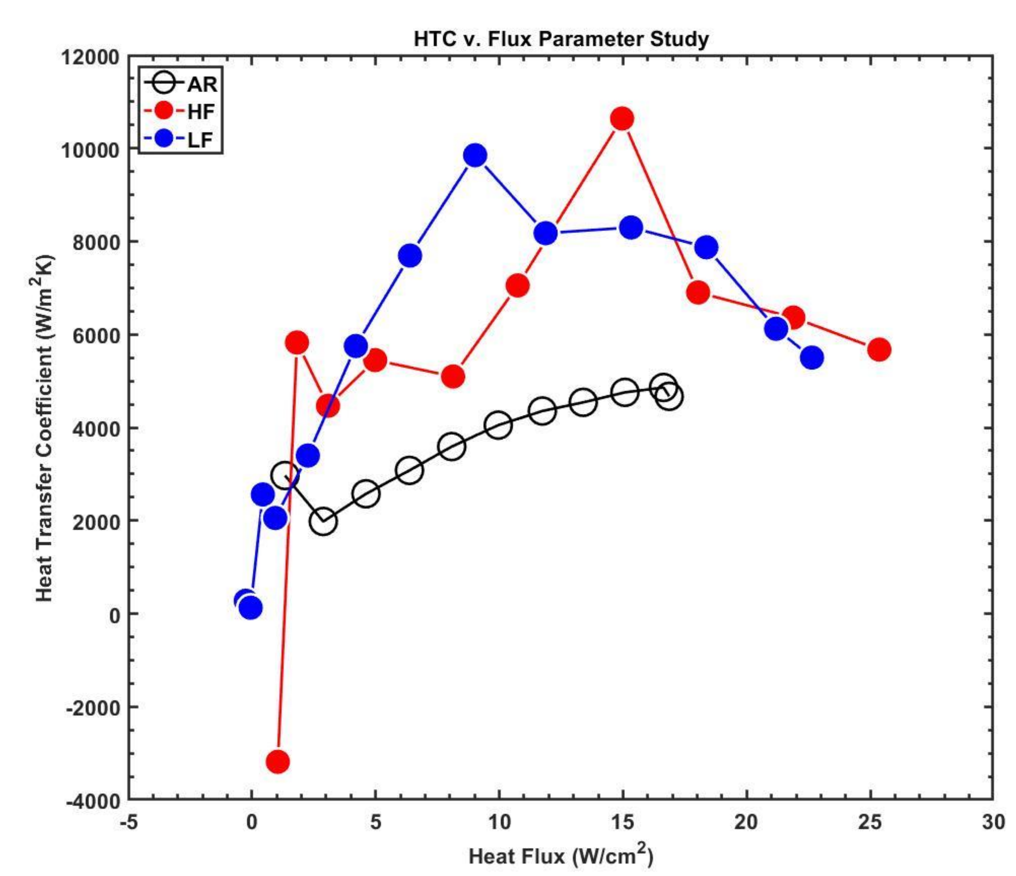
METHODS AND RESULTS

We decided to study the effects of FLSP on silicon surfaces using PF-5060, a dielectric, as the working fluid in a pool boiling setup. This study is relevant as pool boiling is currently being used in the immersion cooling of electronic components.

The image to the right is a cross-section of the sample used for testing. Thermocouples are used to get temperature, and temperatures are used to calculate the heat fluxes assuming 1-D conduction. The PEEK bushing is used for insulation to reduce radial losses.







Three samples were created, one polished acting as a baseline (AR for as received), and the other two FLSP surfaces with a fixed pulse count of 308 and a variable fluence. The first surface, denoted by LF for low fluence, had a fluence of 3.32 J/cm^2. The second surface, denoted HF for high fluence, had a fluence of 16.6 J/cm^2.

The FLSP surfaces both had an increase in CHF and a decrease in superheat compared to the polished runs. The high fluence sample had the highest CHF at 25.36 W/cm^2, a 165.9% increase from polished, at 15.29 W/cm^2. The low fluence had a CHF of 22.64 W/cm^2, a 148.1% increase from polished. The decrease in superheat led to the rise in maximum HTC for both FLSP samples. The high fluence sample achieved the maximum HTC at 10642 W/m^{2}K, a 245.2% increase on polished, 4339.5 W/m^{2}K. The low fluence sample had a maximum HTC of 9852.6 W/m^{2}K, a 227.0% increase on polished.

The increase in HTC and CHF is most likely due to an increase of nucleation sites from the FLSP structures as well as the increased wicking ability of the structures. The high fluence sample performed better overall compared to the low fluence sample, however FLSP in general outperformed silicon regardless of structure.

The high fluence sample shows boiling inversion starting at a heat flux of 8.130 W/cm^2 and continuing to 14.96 W/cm^2. This is most likely due to extra nucleation sites activating during those fluxes causing the superheat to reduce as more energy is pushed into the fluid.

ACKNOWLEDGMENTS

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