Secondary Pool Boiling Effects

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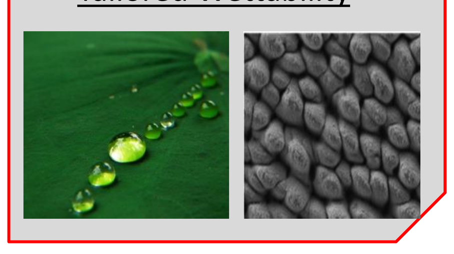
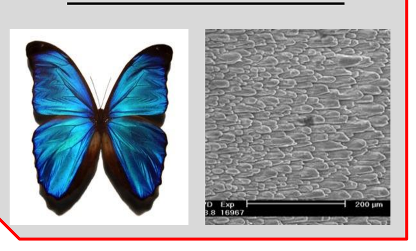
Motivation

- Femtosecond Laser Surface Processing (FLSP) has the ability to functionalize metallic surfaces with self-organized micro/nanostructures capable of the following:

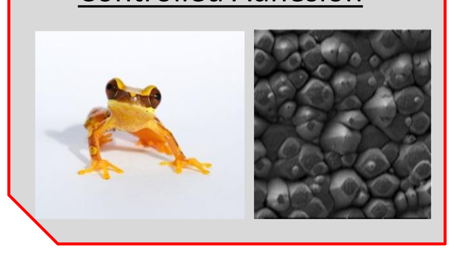
Tailored Wettability



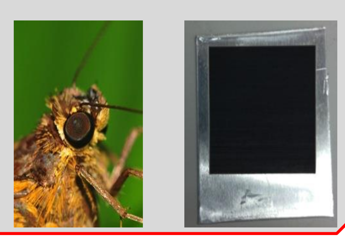
Directional Surfaces



Controlled Adhesion

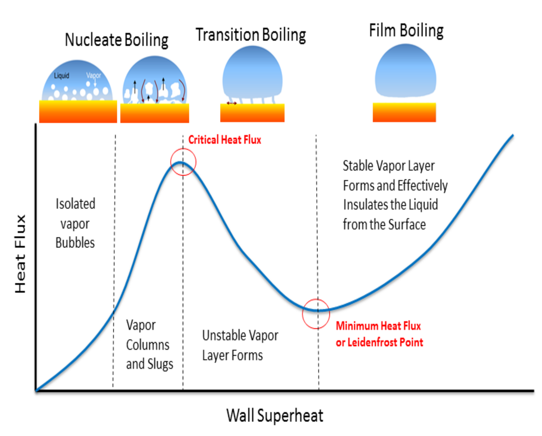


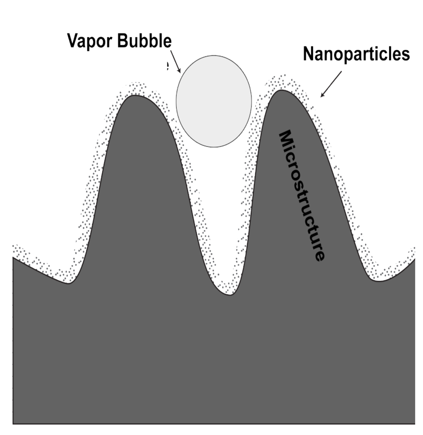
Anti-Reflection/Wideband Absorption



Heat Transfer Application

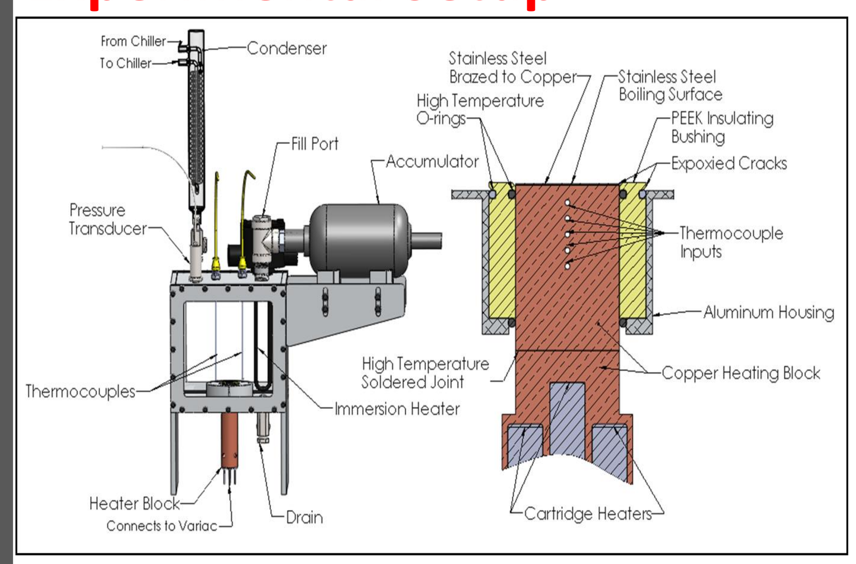
- Increase temperature range of efficient nucleate boiling regime
- Increase Critical Heat Flux
- Increase effective Heat Transfer Coefficient



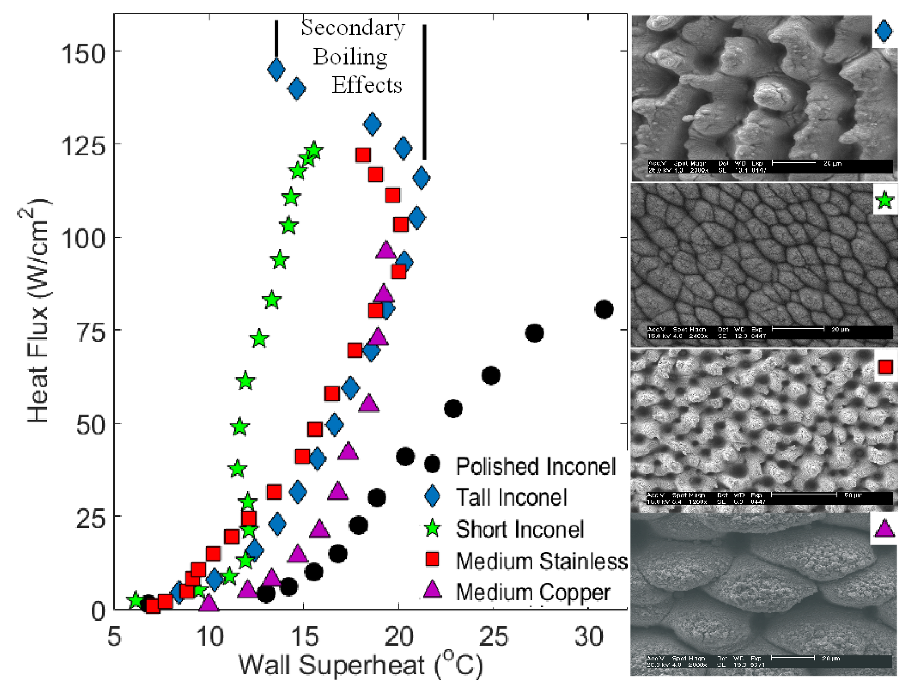


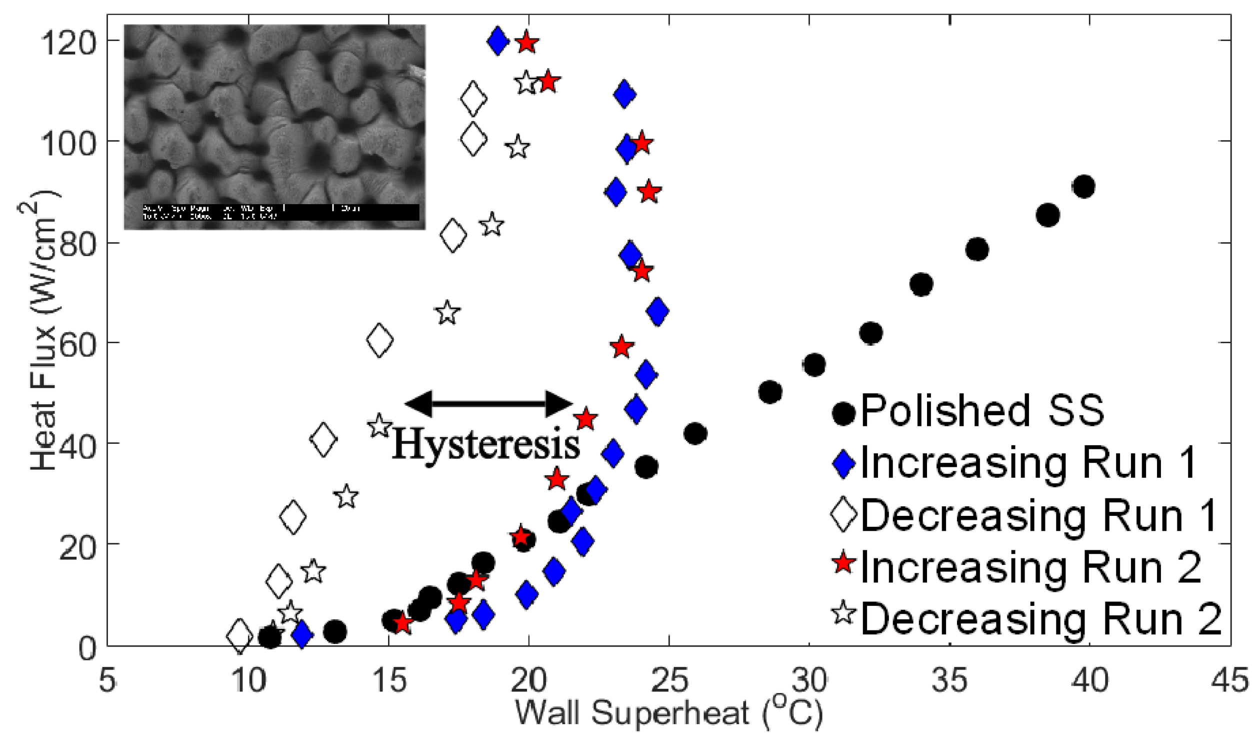
Pool Boiling Heat Transfer Data with Secondary Boiling Effects

Experimental Setup



- The pool boiling experimental setup is used to measure the heat flux between a surface and liquid interface
- The heat flux is calculated from the measured temperature gradient and then the surface temperature is calculated based on the heat flux
- Heat flux is plotted with respect to surface wall superheat temperature
- Critical heat flux is determined by an instantaneous increase in the surface temperature due to the insulating effects of film boiling
- A new phenomenon referred to as secondary boiling effects has been observed





- Five FLSP surfaces with varying materials were tested for pool boiling enhancement
- Secondary boiling effects refers to a unique "hook back" in the boiling curve near the CHF
- This hook back is very beneficial because it corresponds to a significant enhancement in the heat transfer coefficient

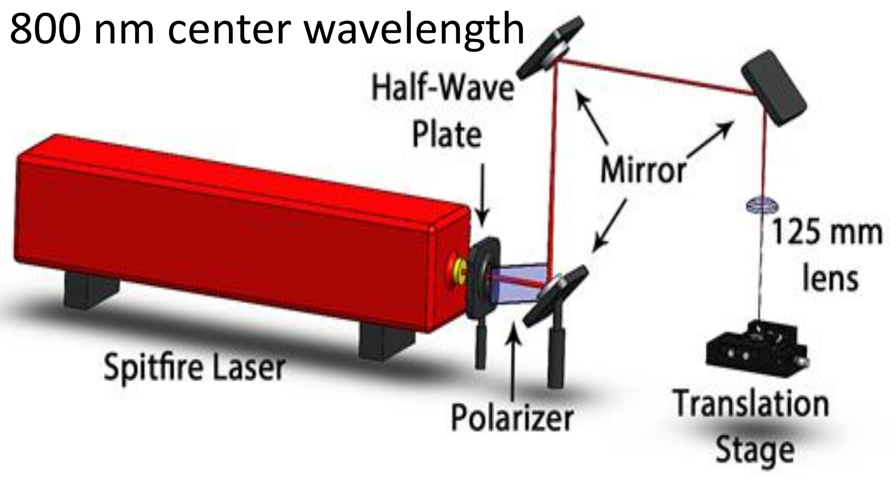
Sample	Peak-to-Valley Height (µm)	Surface Roughness (µm)	Surface Area Ratio	Biot Number
Tall Inconel	55.2	12.2	12.2	0.21
Short Inconel	9.1	1.8	1.8	0.03
Medium SS	35.8	7.4	7.4	0.135
Medium Copper	37.5	8.6	8.6	0.006
Hysteresis SS	27.1	5.1	5.1	0.1

- Secondary boiling effects also result in a hysteresis in the boiling curve.
- This is displayed when the heat flux is increased and then decreased. The decreasing curve displays a completely different HTC
- Using the geometric characterization of each surface it can be seen that there is a distinct trend with respect to microstructure height
- It is also observed that the microstructure material plays a role in whether or not secondary boiling effects are present.

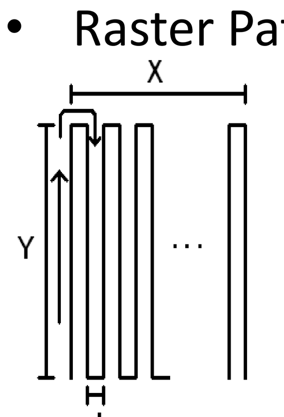
Nano and Microstructure Fabrication

Machining Process

- Spectra-Physics Spitfire Laser
  - 50 fs
  - 1 mJ maximum pulse energy
  - 1 kHz repetition rate
  - 800 nm center wavelength

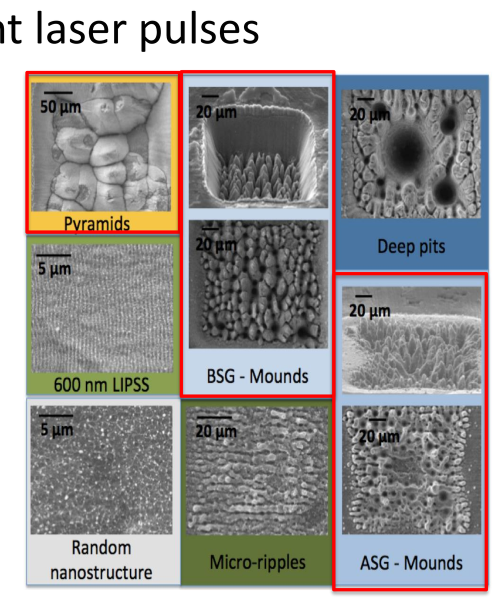


- Raster Path On Sample



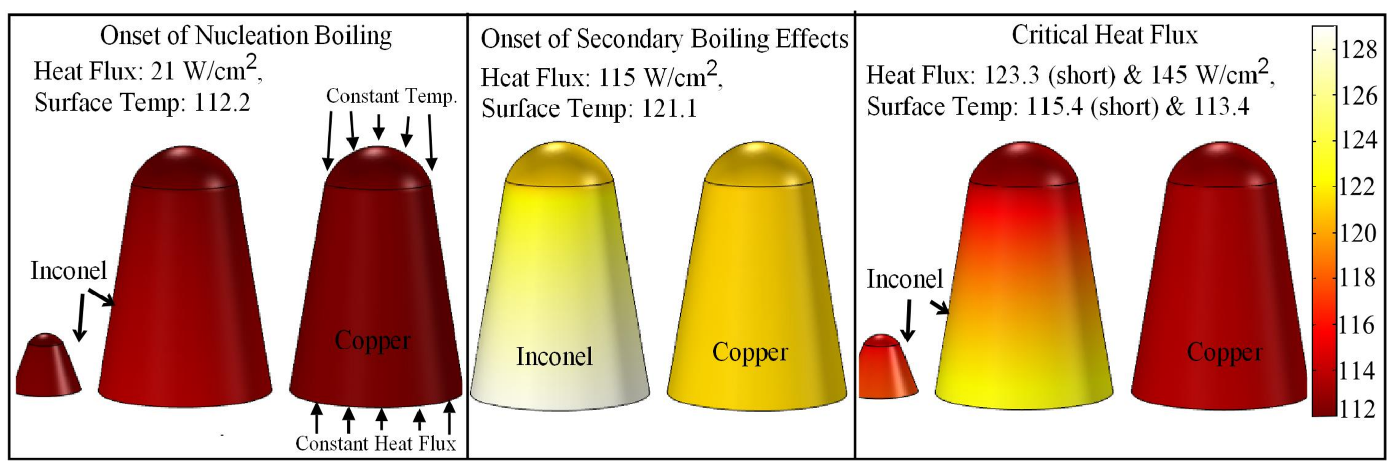
- Nanoparticle redeposition and surface fluid flow create micro and nano-structures.

- Range of Structures
  - A variety of structures can be created through the control of laser fluence and number of incident laser pulses
- Structures of interests for heat transfer include:
  - Pyramids
  - BSG-Mounds
  - ASG-Mounds



Secondary Boiling Effects Mechanism

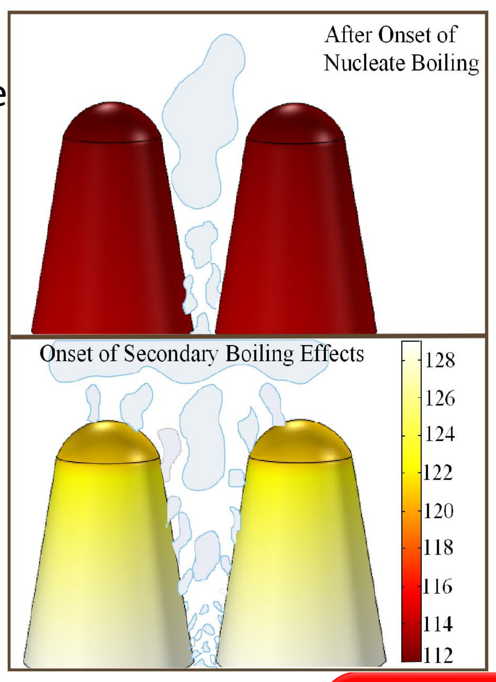
- It has been found that secondary boiling effects are a result of a temperature gradient inside the microstructure
- COMSOL was used to estimate the temperature drop inside the microstructures
- This temperature drop is dependent on microstructure height and material thermal conductivity



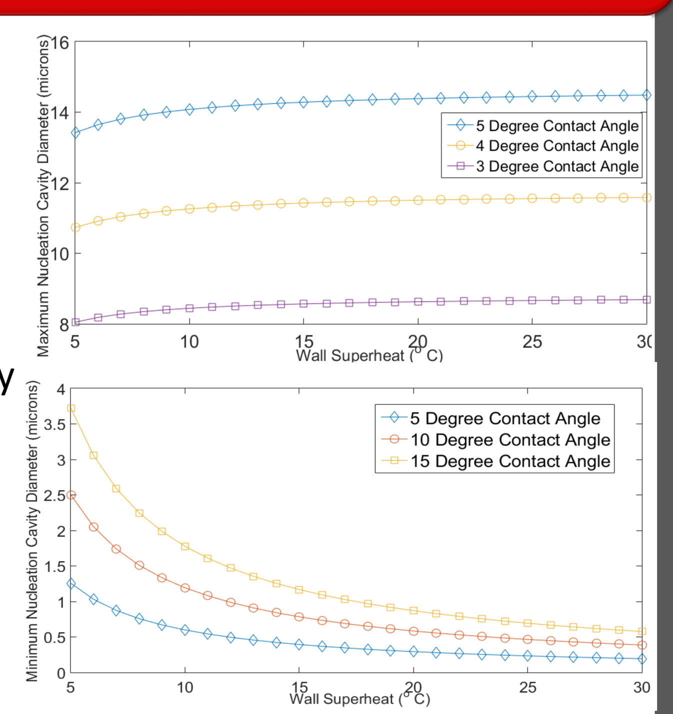
- The possibility of secondary boiling effects can be predicted by the Biot number, which describes if temperature gradients are present
- Microstructures with Biot numbers over .1 will have non uniform temperatures
- Only the FLSP surfaces with Biot numbers above .1 displayed secondary boiling effects

$$Bi = \frac{h * Lc}{k}$$

- As the heat flux increases so does the temperature drop along the structures
- This results in a shift in nucleation dynamic
- Nucleation spreads from the bottom (hotter) to the top (cooler) of the microstructure as the whole surface heats up and the gradient increases
- Nucleation also becomes more dense at the bottom of the microstructures due to the activation of smaller nucleation cavities

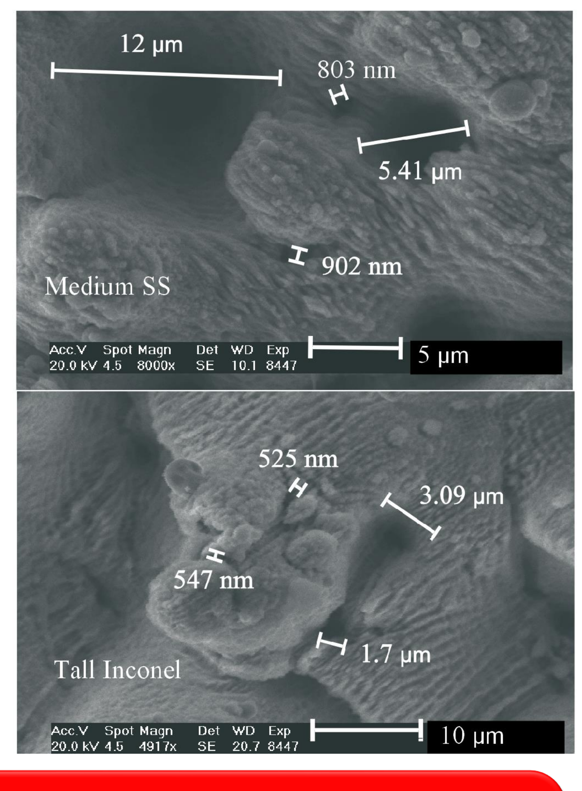


- Active nucleation cavities sizes can be estimated using the given equation
- Active cavities are only located on the side of the microstructures
- The large pits in between structures will be flooded



$$Dmax, Dmin = \frac{\delta_t C_2}{C_1}\frac{\Delta T_w}{\Delta T_w + \Delta T_{sub}} \times \left[1 \pm \sqrt{1 - \frac{8 C_1 \sigma T_{sat}(\Delta T_w + \Delta T_{sub})}{\rho_v h_{fg} \delta_t (T_w)^2}}\right]$$

- A wide range of a few micron to submicron diameter potential nucleation sites must be present
- Secondary boiling effects are due to a combination of temperature gradient (low thermal conductivity and tall microstructure height) and an wide range of potential nucleation cavities along the height of the microstructure



Acknowledgements

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