Femtosecond Laser Surface Processing Techniques and Applications in Electrochemistry and Nucleate Pool Boiling

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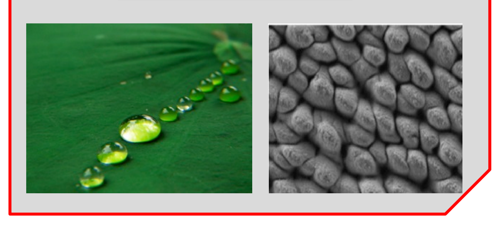
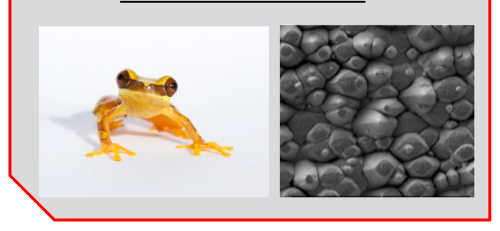
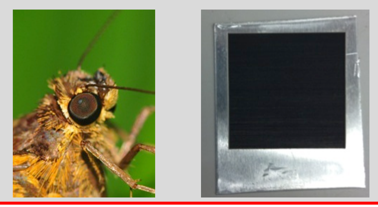
Motivation

- Use of femtosecond laser fabricated multi-scale structures to control material surface properties including:





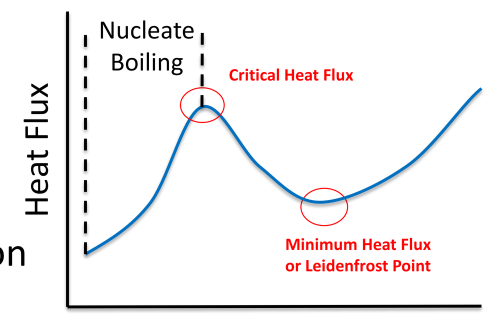


Electrochemical Application

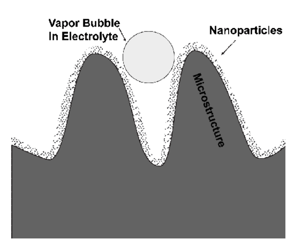
- Decrease power consumption of commercial electrolysis
- Facilitate bubble formation and release
- Reduce bubble coverage of electrode surface

Heat Transfer Application

- Increase temperature range of efficient nucleate boiling regime
- Increase efficiency of cooling hot metals in metallurgical and power plant industry
- Leidenfrost droplet motion can be controlled and used for various transport applications



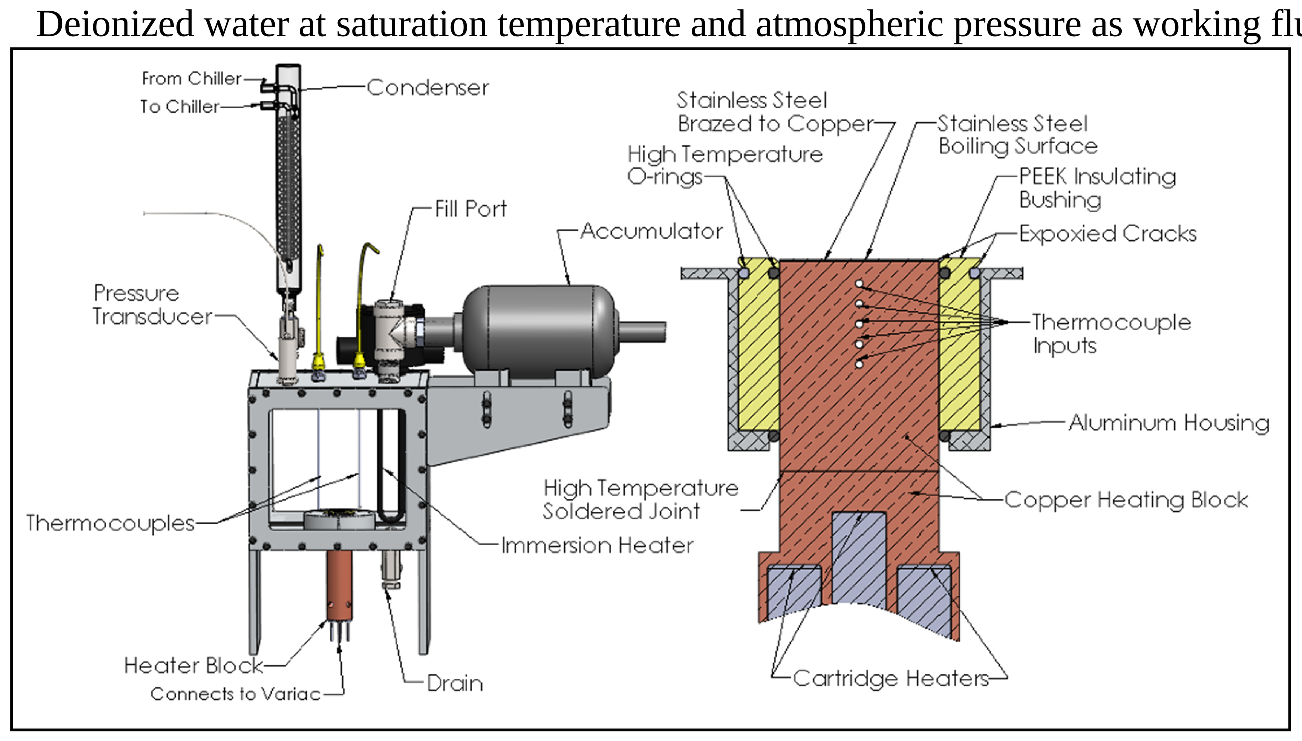
- Bubble size and behavior in boiling and electrolysis can be controlled by surface structures



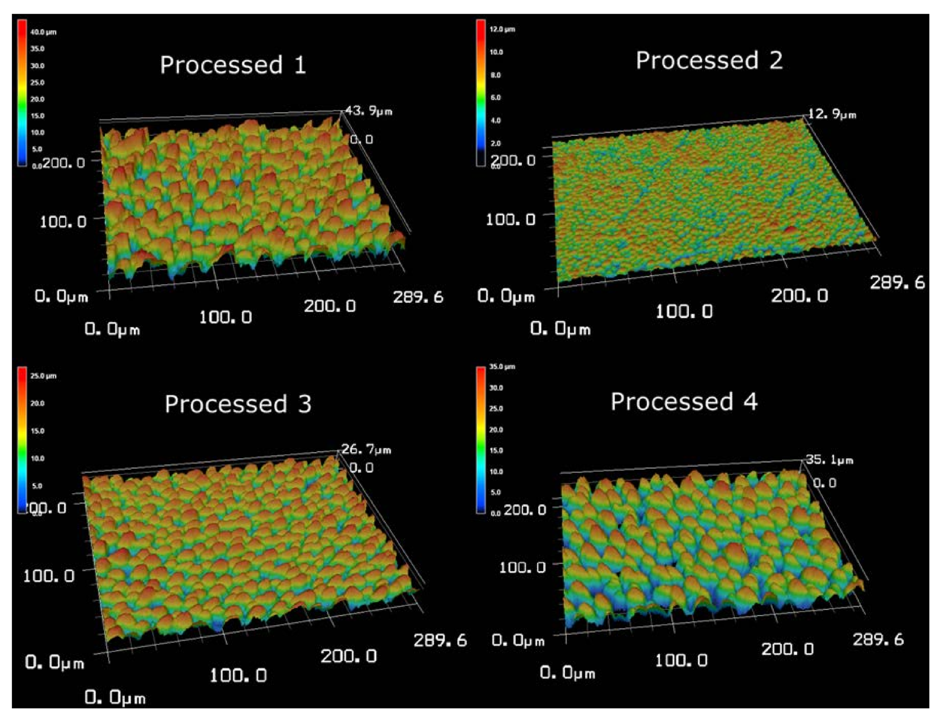
Heat Transfer

Experimental Setup

- Closed system with temperature and pressure control
- Processed stainless steel wafer brazed to a copper heating block
- Calculated heat flux and interpolated surface temperature from thermocouple measurements
- Deionized water at saturation temperature and atmospheric pressure as working fluid



Surface Structures

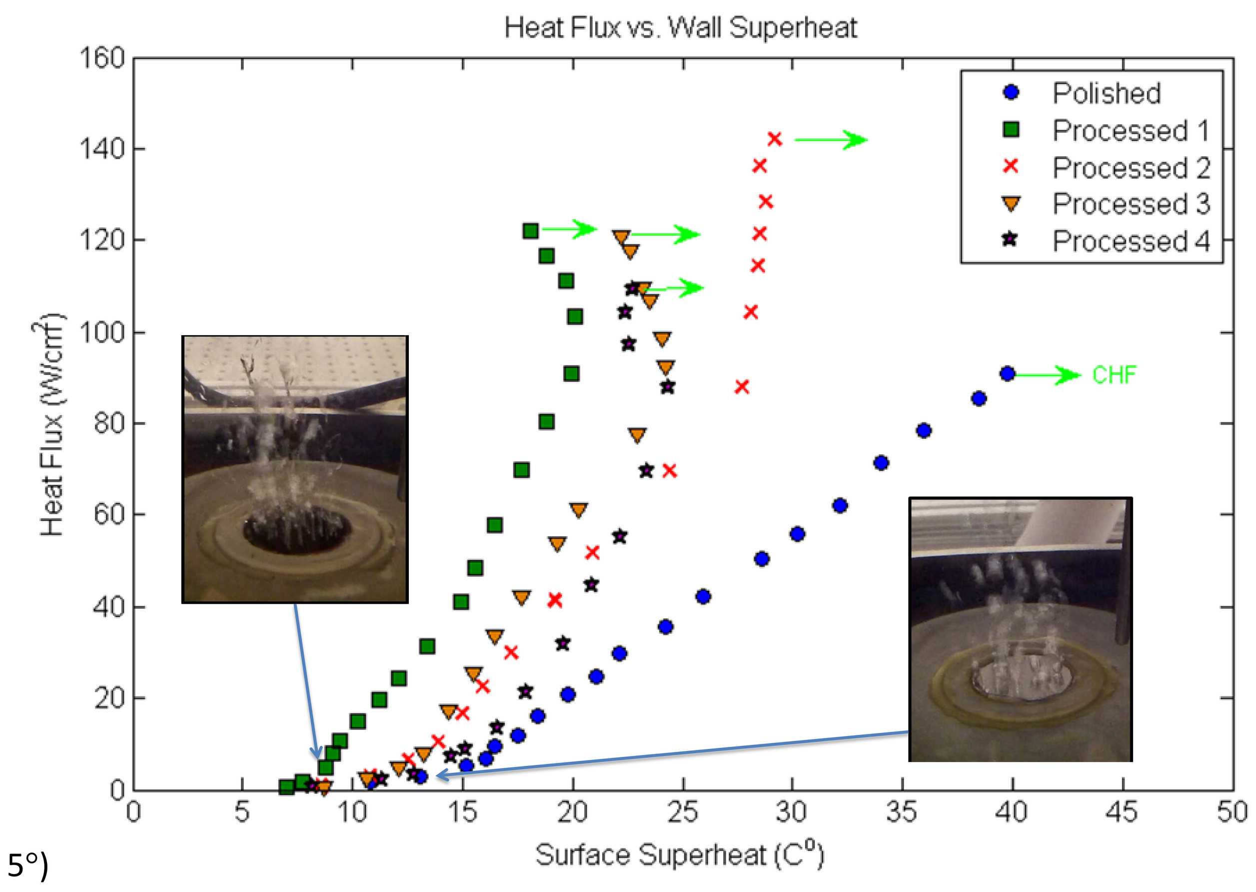


- Surfaces were designed to have varying height and spacing
- All surfaces were processed to be superhydrophilic (contact angle < 5°)
- An additional polished (mirror finish) stainless steel surface was created for reference (not pictured)

	Peek to Valley Height (μm)	Surface Area Ratio	Surface Roughness (R_{rms})
Processed 1	35.8	4.7	7.4
Processed 2	7.11	3.85	1.44
Processed 3	22.3	3.79	4.6
Processed 4	31.3	3.82	7.8

Results

- Effectively shifted boiling curve to the left and increased CHF
- Increased heat transfer coefficient up to 7.5 times due to increase in potential nucleation sites and increased surface area ratio
- Increased critical heat flux by 1.5 times due to increased wettability of the surface and capillary action between microstructures
- Reduced surface temperature at which nucleate boiling occurs

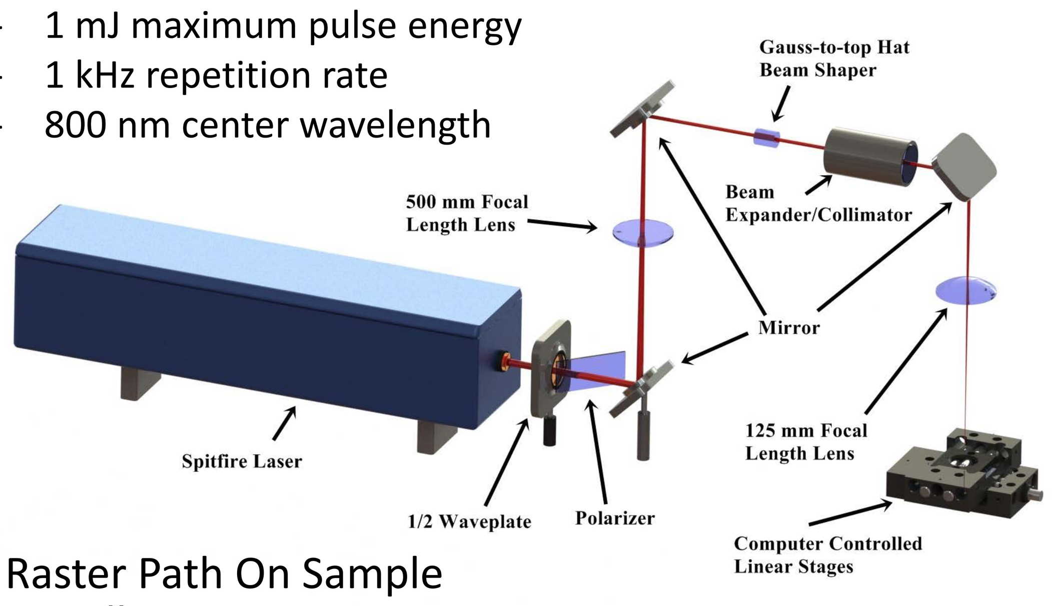


	Polished	Processed 1	Processed 2	Processed 3	Processed 4
Critical Heat Flux (w/cm^2)	91	122	142	118	109
Heat Transfer Coefficient (W/m^2K)	22,900	67,400	48,600	52,000	47,800

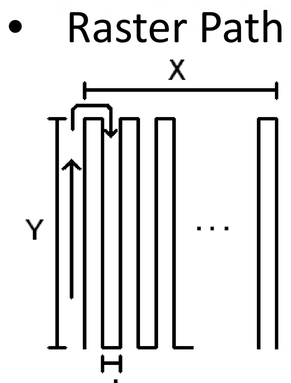
Nano and Microstructure Fabrication

Machining Process

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



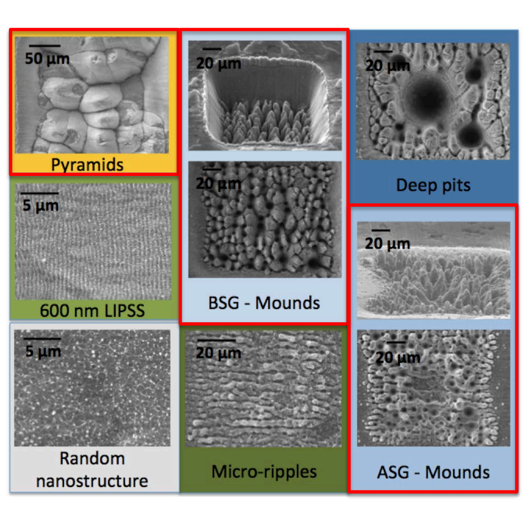
- Raster Path On Sample



- 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 electrolysis and heat transfer include:
  - Pyramids
  - Below Surface Growth (BSG-Mounds)
  - Above Surface Growth (ASG-Mounds)

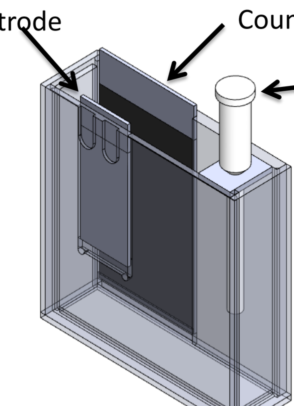


Electrolysis

How can power consumption of electrolysis be reduced?

Method

- Custom 3 terminal electrochemical cell
- Princeton Applied Research VersaSTAT 3
  -Voltage control and current monitoring
- 3M KOH electrolyte
- Sample Material: 316 SS

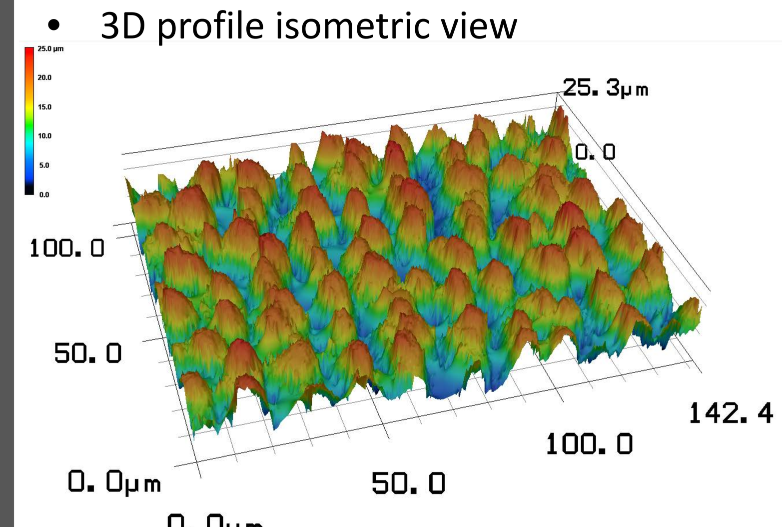


Structured Electrodes

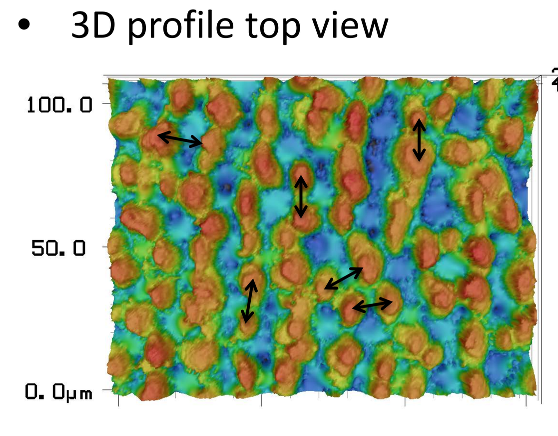
- Hydrophilic surfaces attract electrolyte, pushing bubbles off of surface
- BSG mounds used for the following studies

Structure Parameters of Interest

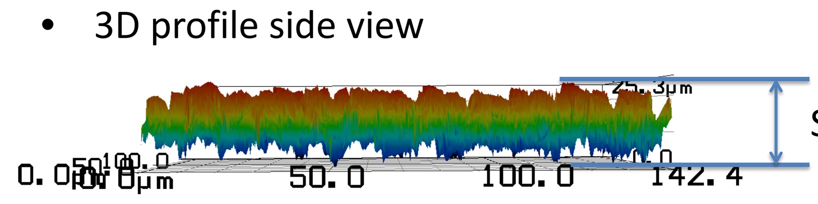
- 3D profile isometric view



- 3D profile top view



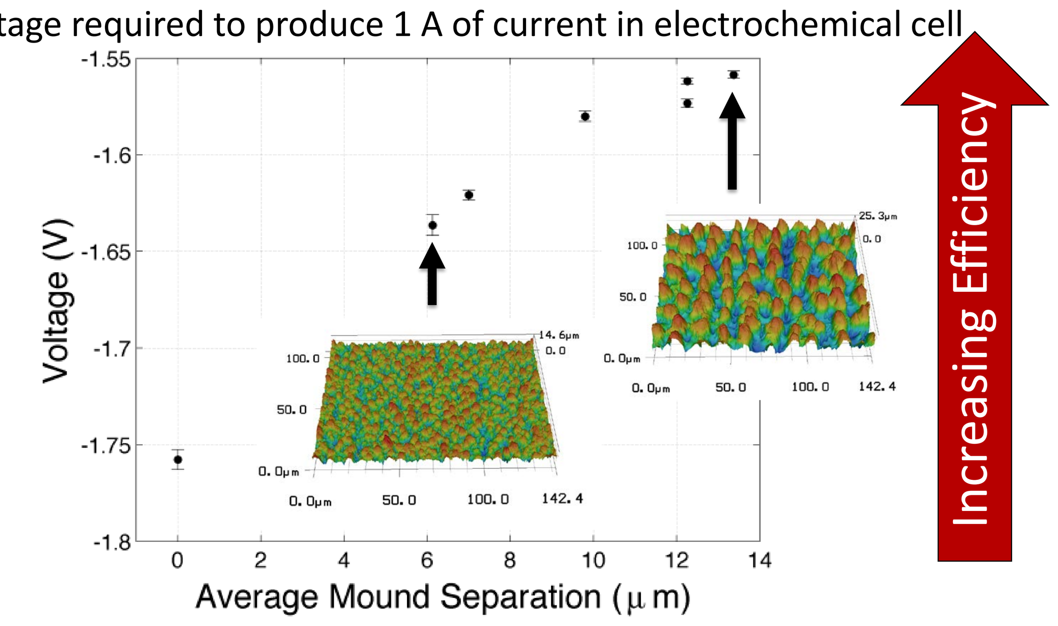
- 3D profile side view



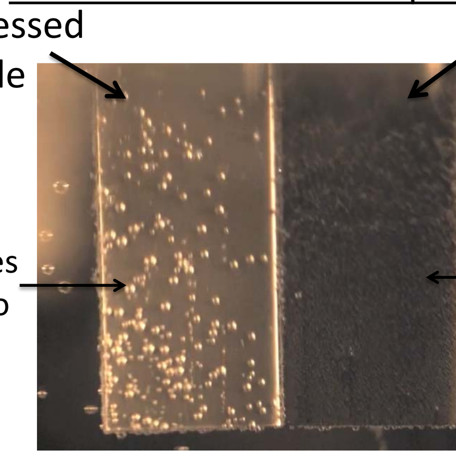
Results

- **Increase in average mound separation directly decreases power consumption**
- **10.46 % maximum power reduction to date**

Voltage required to produce 1 A of current in electrochemical cell



Bubble Production Comparison



Acknowledgements

This work Is funded through a grant by the Nebraska Center for Energy Sciences Research (NCESR)

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