Femtosecond Laser Surface Processing (FLSP) of Silicon for Pool Boiling Enhancement Using Dielectric PF-5060

NEBRASKA CENTER FOR ENERGY SCIENCES RESEARCH

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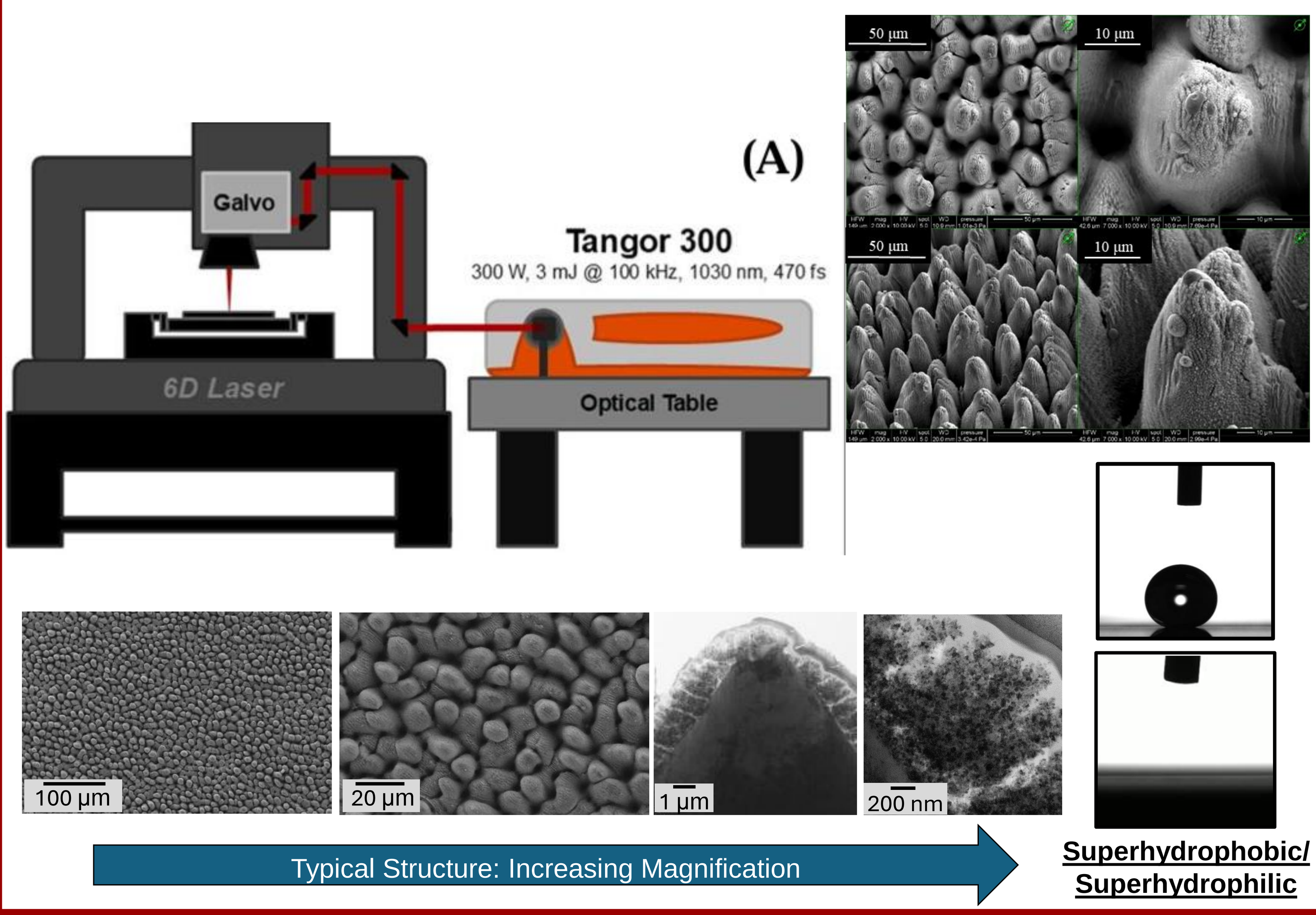
CEFS Center for Electro-Optics & Functionalized Surfaces

Femtosecond Laser Surface Processing (FLSP)

Overview

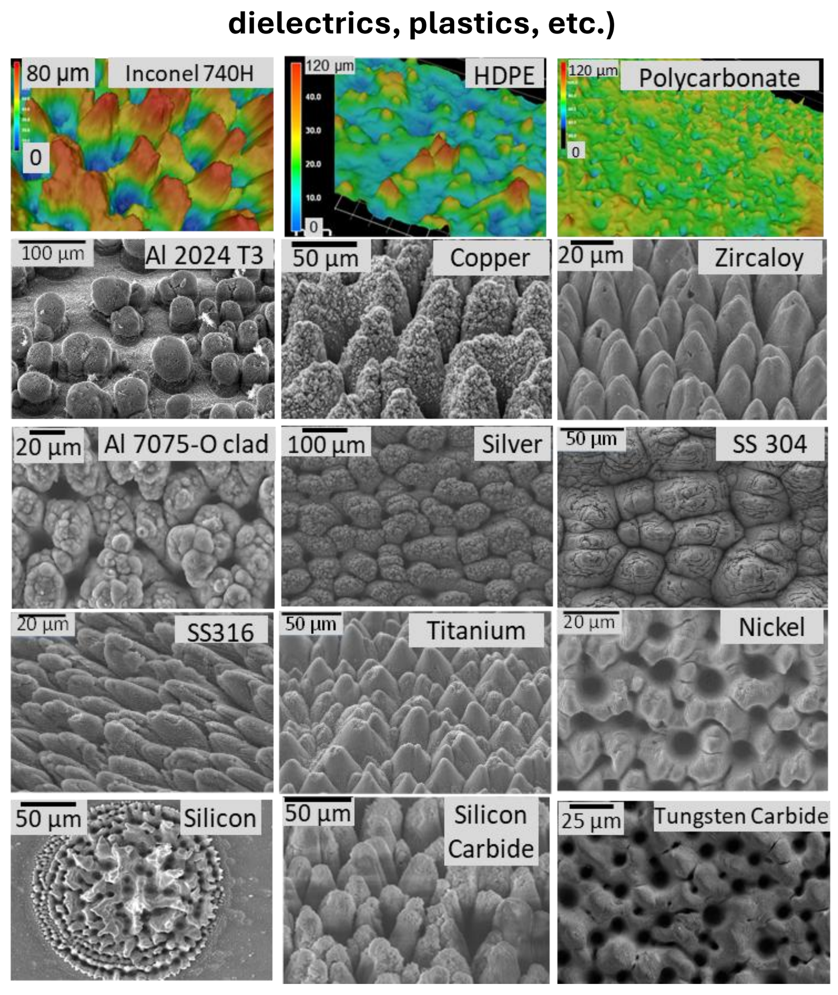
- FLSP is a transformational approach to efficiently adjust surface morphology using **finely controlled laser-matter interactions**.
- The surface properties of a material are modified **directly** and **permanently** by producing quasi-periodic hierarchical micro- and nano-scale surface features, along with surface and subsurface microstructure and chemical changes.
- The introduction of multiscale surface features, controlled surface chemistry, and controlled subsurface crystal microstructure **enable the control of surface properties without coatings or paints**.
- FLSP has a myriad of military/civilian applications, ranging from antimicrobial surfaces to enhanced heat transfer.



Critical Strengths of FLSP

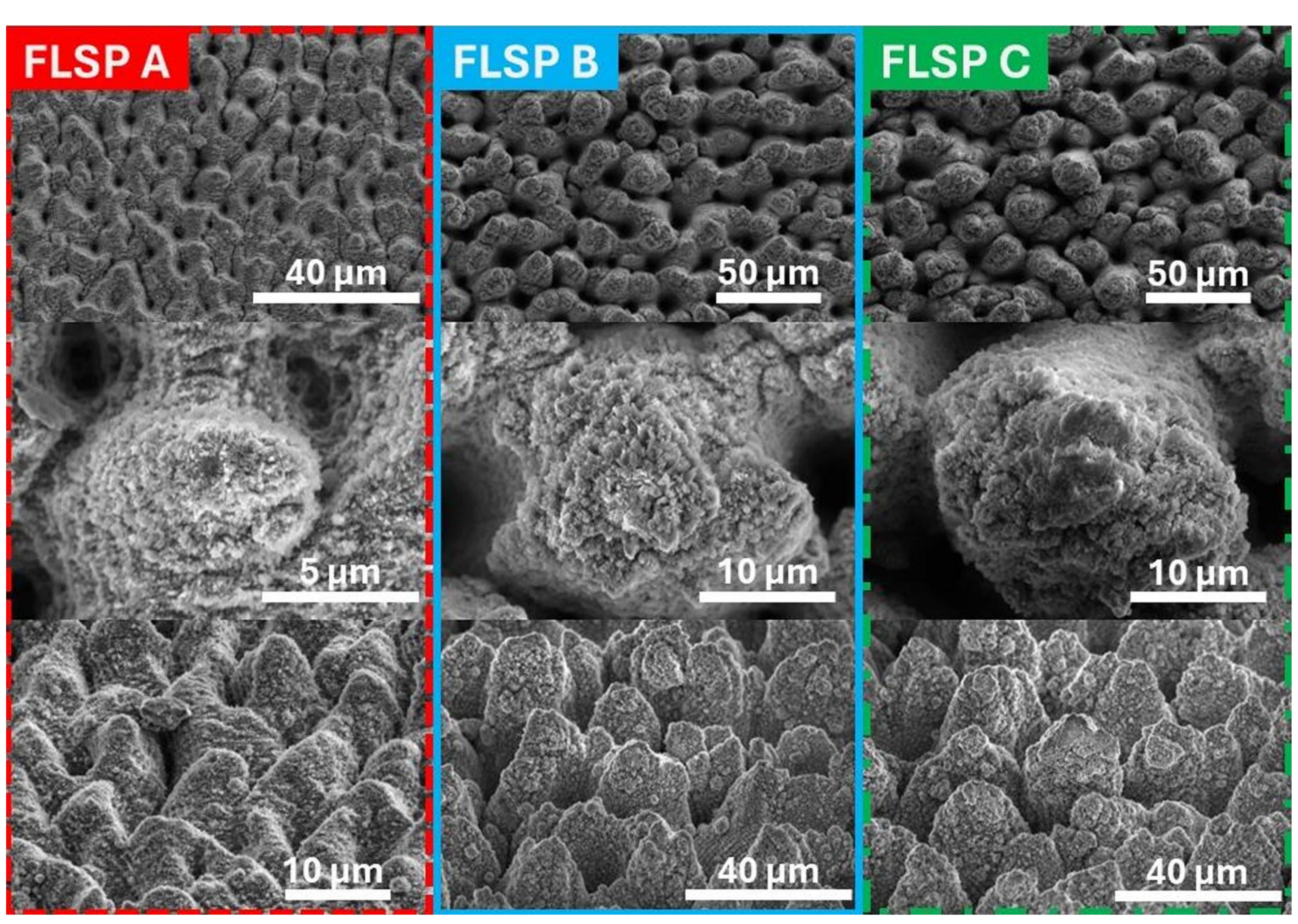
- **Multiscale structures in a single step**
  Control over micro/nanoscale features, chemistry and subsurface crystal structure.
- **Permanency**
  Functionalization through shaping of substrate – retain durability of substrate.
- **Versatility**
  FLSP can be extended to a wide range of materials.
- **Enables optimization**
  FLSP enables optimization of surface properties with fine control of features.
- **Scalability**
  Large areas can be processed by scaling the laser power and repetition rate.
- **Timeliness**
  Resonance with recent ultrafast laser development.

Self-organized structures on a wide variety of materials (metals, ceramics, semiconductors, dielectrics, plastics, etc.)



CEFS has been successful in applying FLSP to every material attempted.

Silicon Test Surfaces

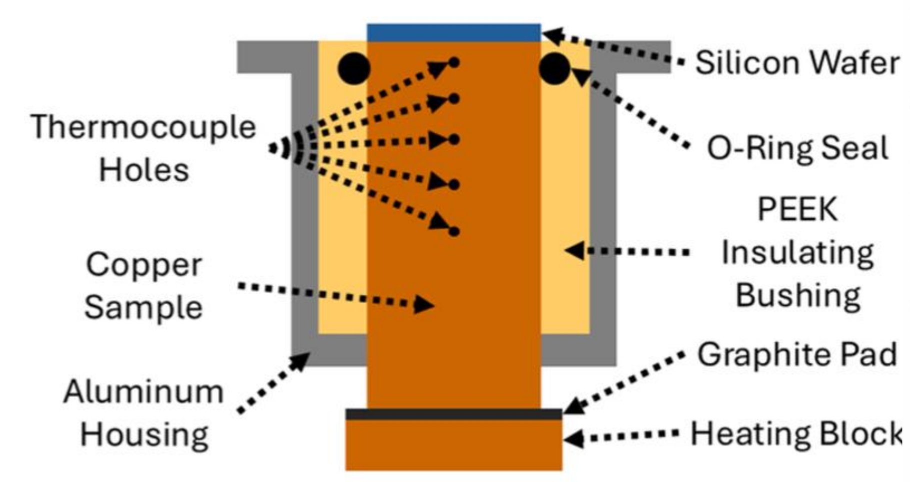


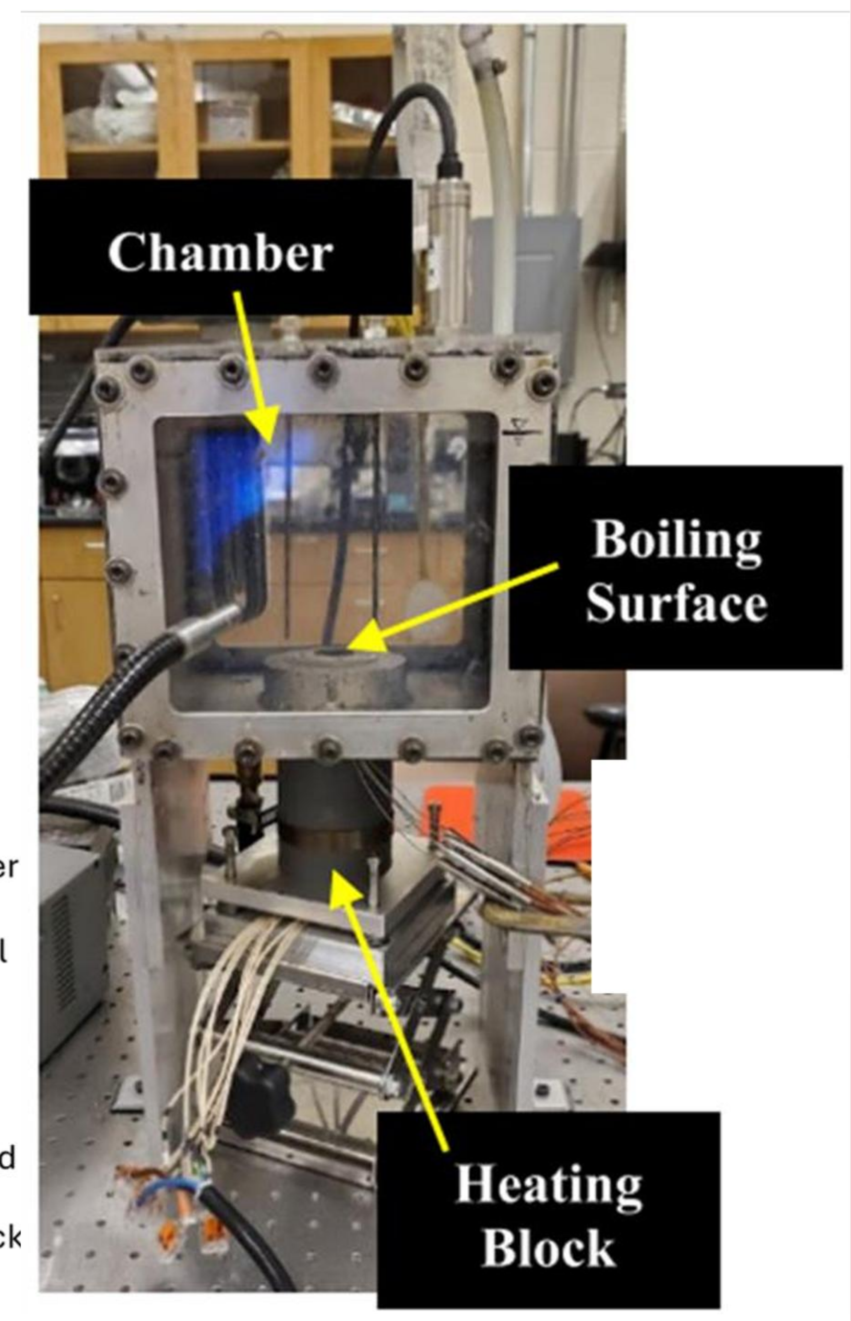
Sample Name	Pulse Count	Rz(µm)	Ra(µm)	SA/A
FLSP A	77	13.4 +/- 2.3	1.5 +/- 0.1	5.5 +/- 0.2
FLSP B	308	39.9 +/- 5.0	6.4 +/- 0.4	7.2 +/- 0.2
FLSP C	513	44.4 +/- 5.6	6.6 +/- 0.4	7.3 +/- 0.2

Pool Boiling

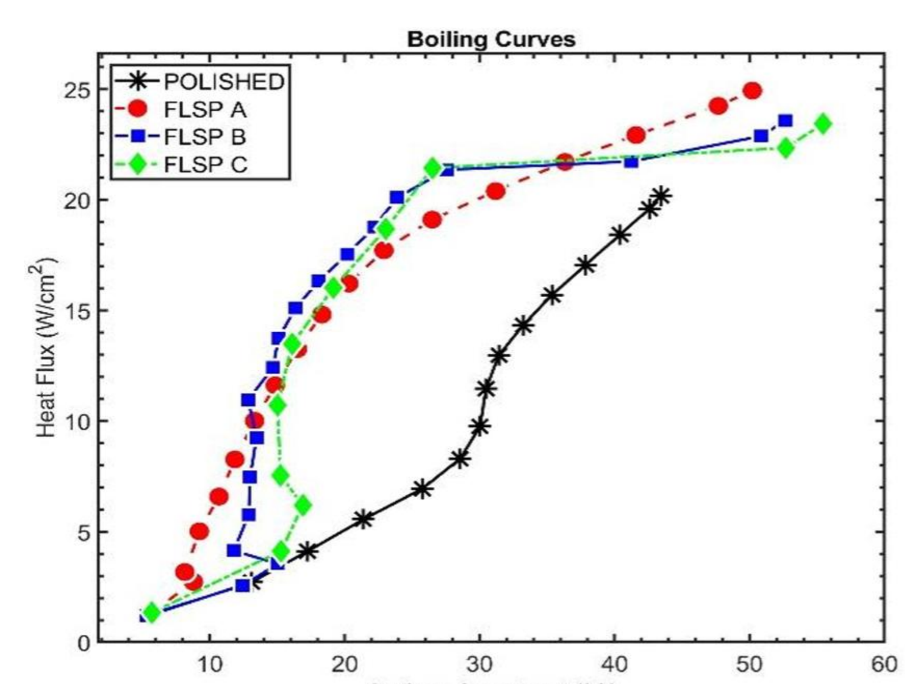
Experimental Setup

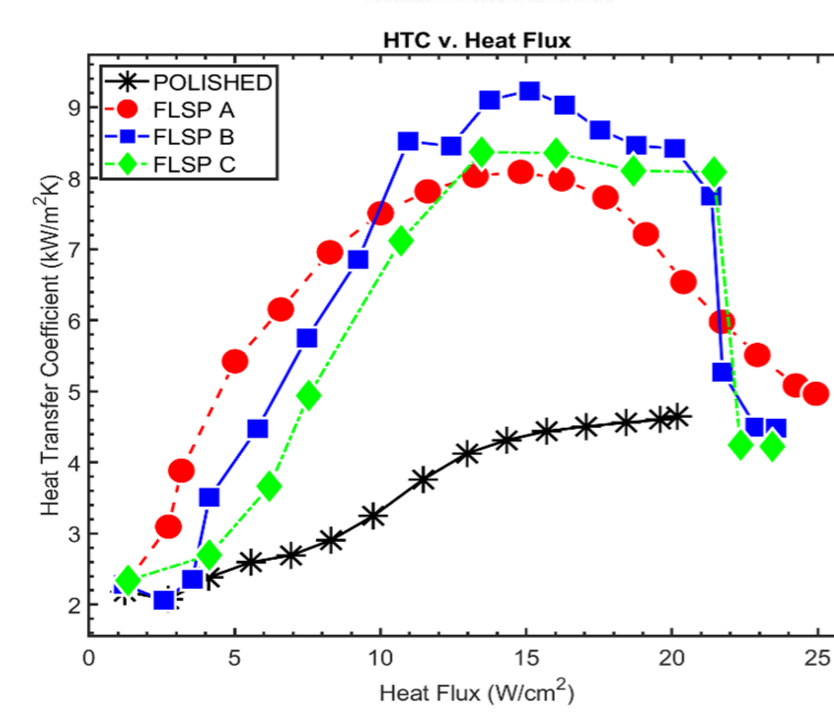
- Primarily Aluminum chamber with insulated Copper heating block
- Graphite heating pad to decrease contact resistance
- Copper sample with five uniformly spaced holes for thermocouples
- Silicon wafer soldered onto copper sample as testing surface
- PEEK insulating bushing to ensure 1-D conduction
- 8 Liters of degassed working fluid
- Steady State for 5 minutes, record data for an additional 2 minutes

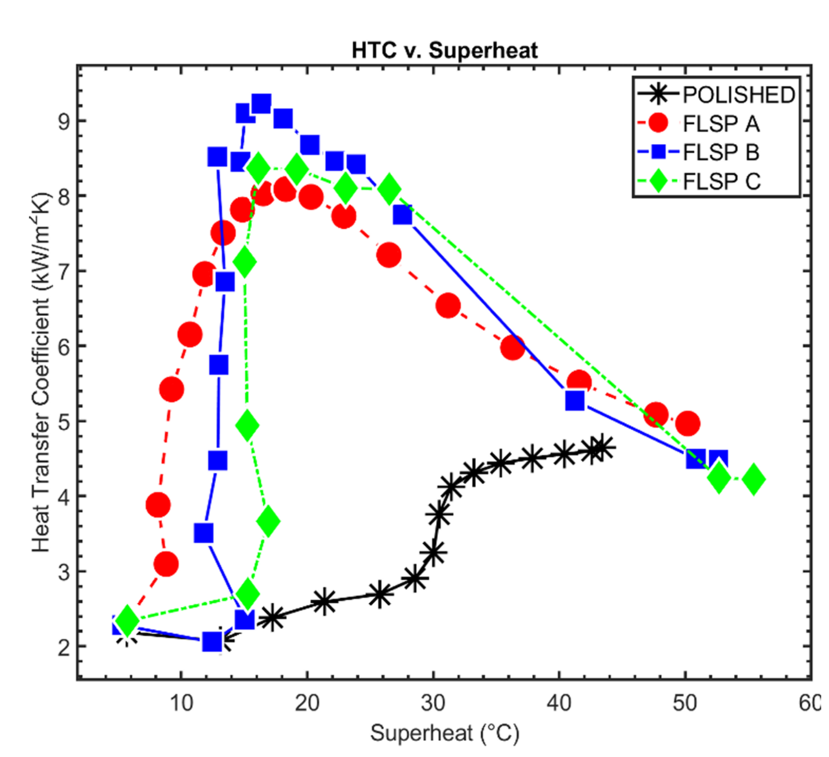




Results







- All FLSP greatly reduce the Surface Superheat from ~5-20W/cm^2
- FLSP A has the largest CHF enhancement (24%) with the smoothest curve
  - Related to smaller structures with less roughness
- All FLSP show a slight CHF enhancement which may result from:
  - Better capillary wicking
- FLSP B has the largest HTC enhancement (99%)
  - Intermediate structure height and roughness
- FLSP C closely follows FLSP B with a slightly lower CHF (16% vs 17%) and lower HTC (80%)
  - Slightly larger structures with a slightly rougher surface
- All FLSP show a large enhancement of HTC (74-99%) which may result from:
  - Better capillary wicking

Sample Name	Pulse Count	HTC_{max} (kW/m2-K)	CHF (W/cm2)
Polished	-	4.65 (-)	20.19 (-)
FLSP A	77	8.09 (+74%)	24.9 (+24%)
FLSP B	308	9.23 (+99%)	23.6 (+17%)
FLSP C	513	8.37 (+80%)	23.4 (+16%)

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