Extending Femtosecond Laser Surface Processing to Materials Important for Heat Transfer Applications

Alfred Tsubaki, Craig Zuhlke, Corey Kruse, Sidy Ndao, George Gogos, and Dennis Alexander
University of Nebraska - Lincoln

Abstract

In this project high surface area, micro/nanostructured surfaces are fabricated using femtosecond laser surface processing (FLSP) for applications in heat transfer.

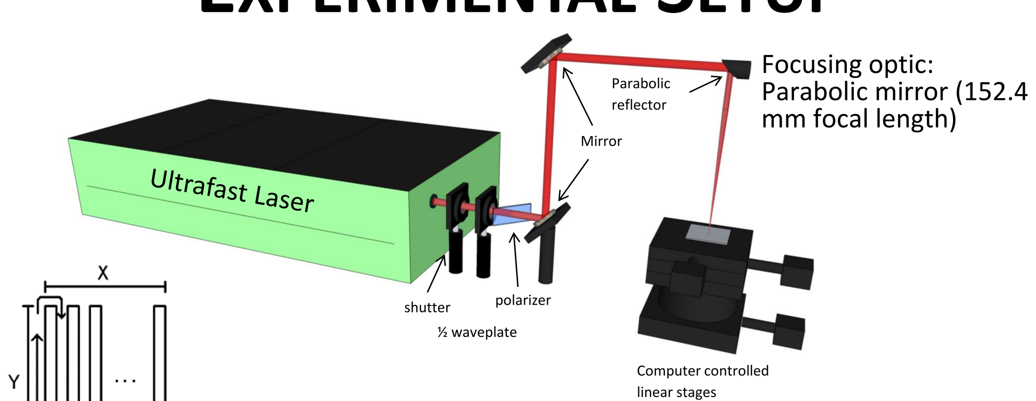
Why Femtosecond lasers?

- Multiscale structures in a single step
- Structure permanency
- Contactless fabrication
- Scalability
- Repeatability
- Versatility

Material Choices?

- Inconel 740H: Newly engineered high temperature alloy for power plant applications
- Zircaloy 4: Common for nuclear power plant applications
- 4H-SiC: Used as stamp for FLSP imprinting and microelectronics
- Copper: High conductivity and often used in critical heat transfer applications

Experimental Setup

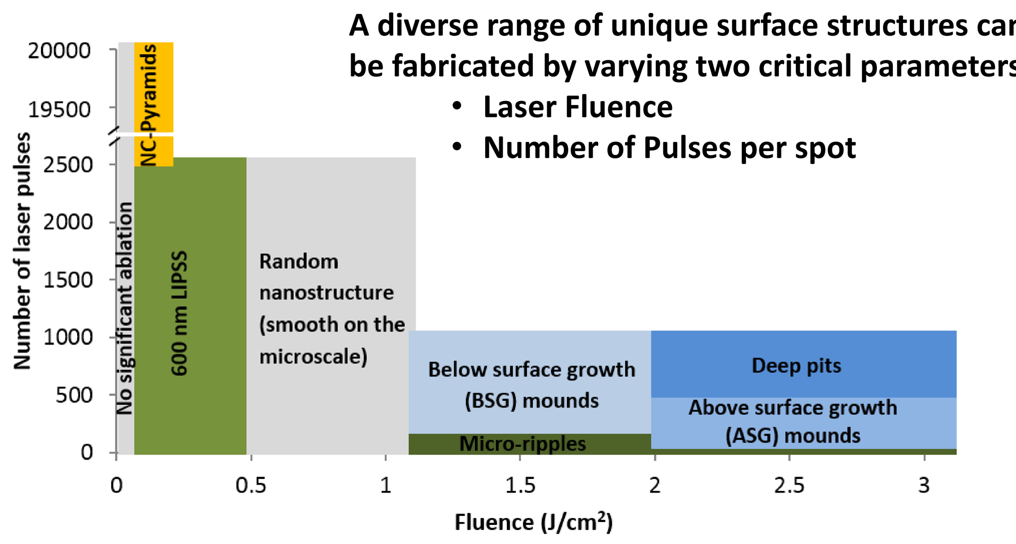


Ultrafast Laser System Specifications		
Laser system	Spitfire, Spectra Physics	Astrella, Coherent
Pulse Energy	1 mJ	6 mJ
Center Wavelength	800 nm	800 nm
Rep Rate	1 kHz	1 kHz
Pulse Duration	80 fs	30 fs

Range of FLSP Structures

A diverse range of unique surface structures can be fabricated by varying two critical parameters:

- Laser Fluence
- Number of Pulses per spot



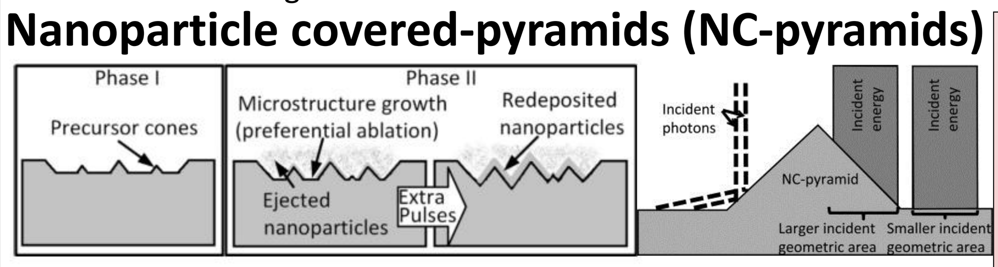
Note: this structure range is for Nickel 200/201 although similar ranges can be found for each material

Dissertation: Zuhlke, C. A. (2012). *ProQuest*. University of Nebraska.

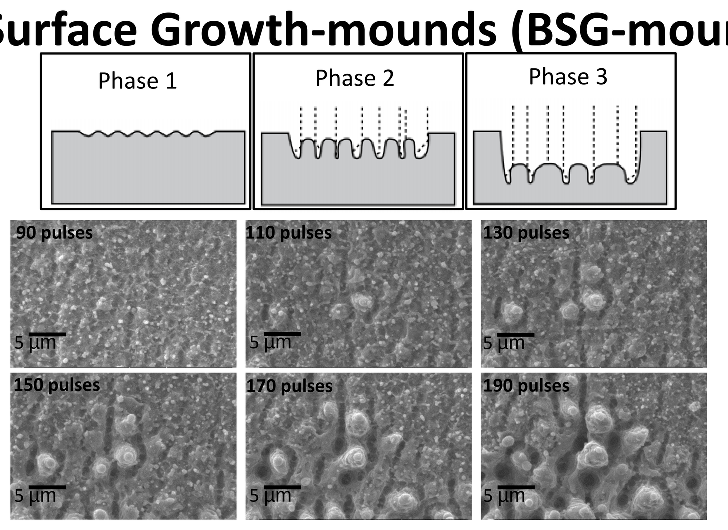
Formation of FLSP Structures

Depending on the fluence of the laser, different formation mechanisms dominate structure growth

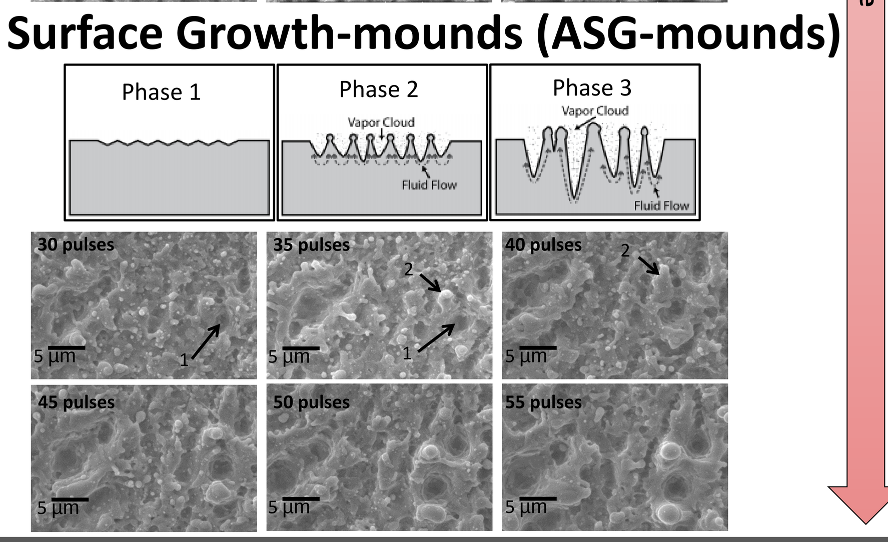
Nanoparticle covered-pyramids (NC-pyramids)



Below Surface Growth-mounds (BSG-mounds)

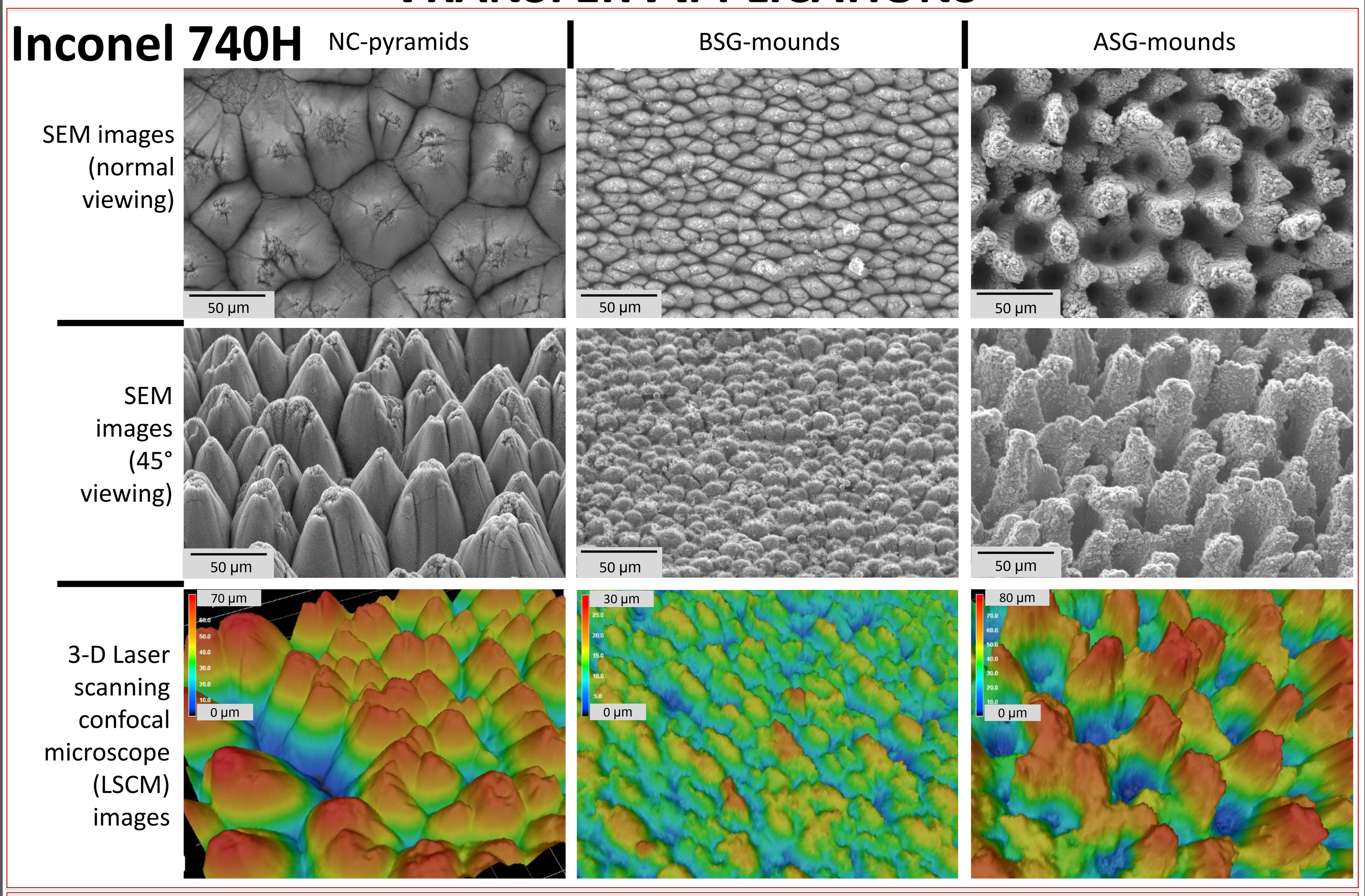


Above Surface Growth-mounds (ASG-mounds)

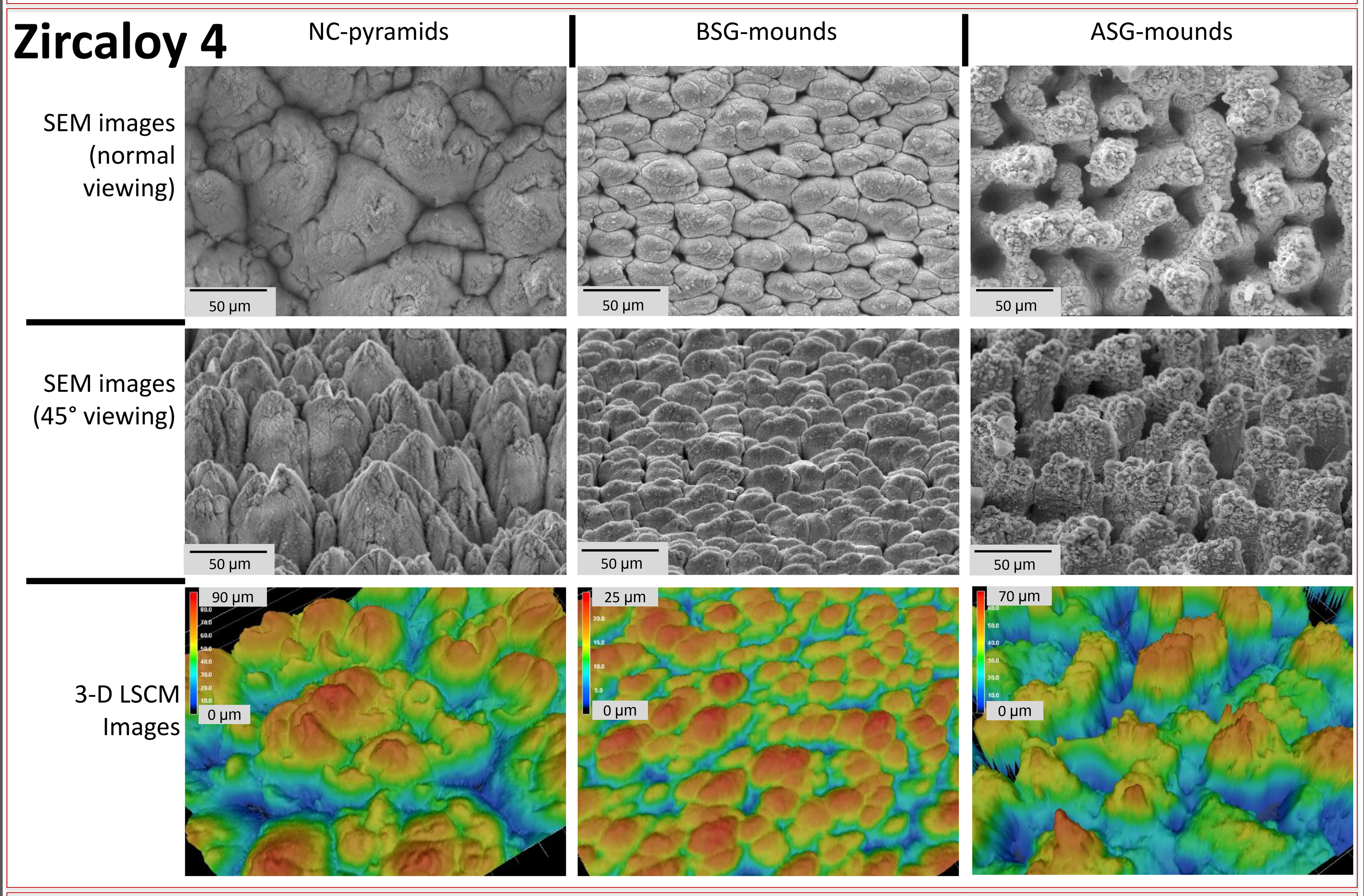


FLSP Structures on Materials Important for Heat Transfer Applications

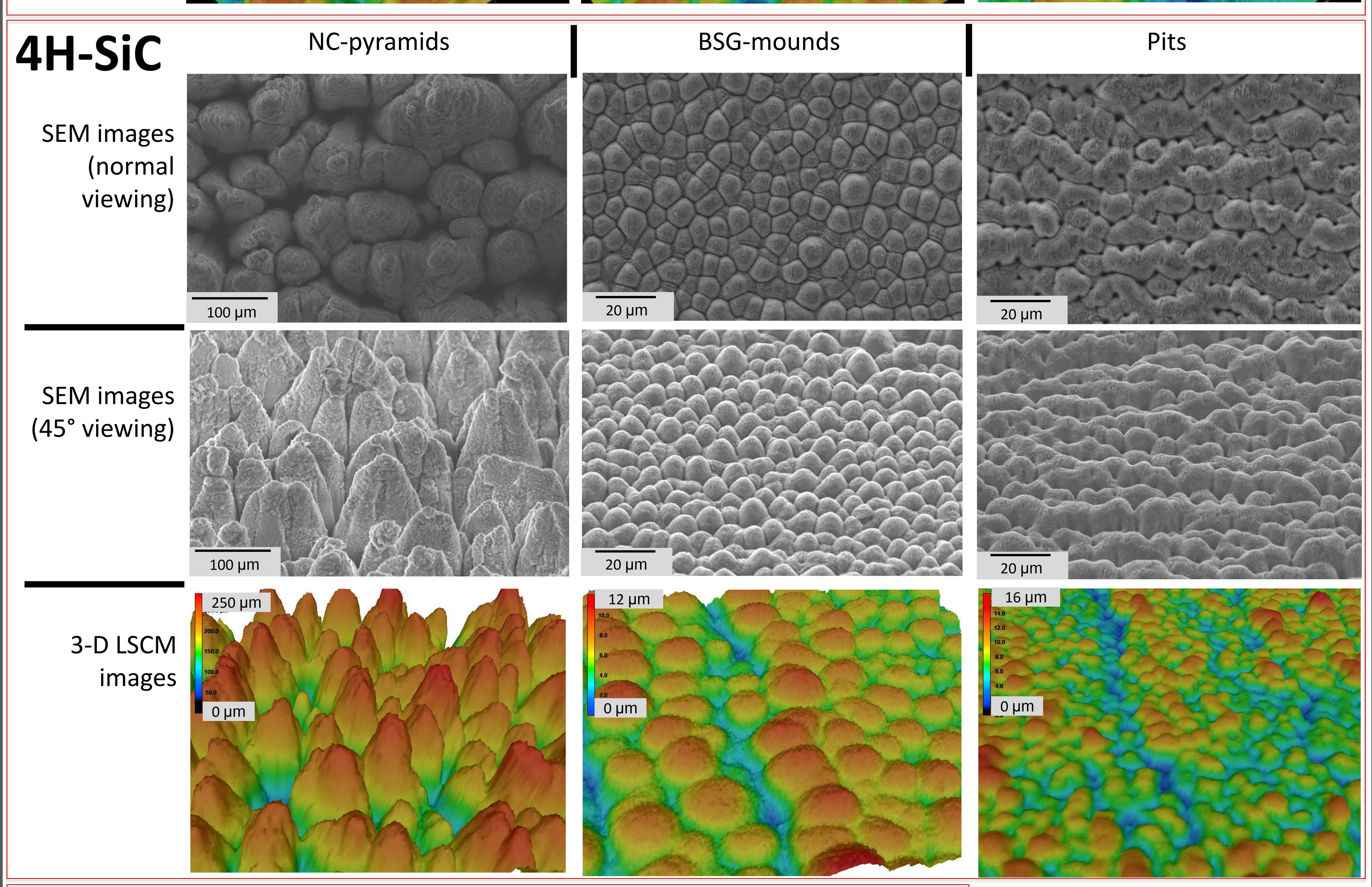
Inconel 740H



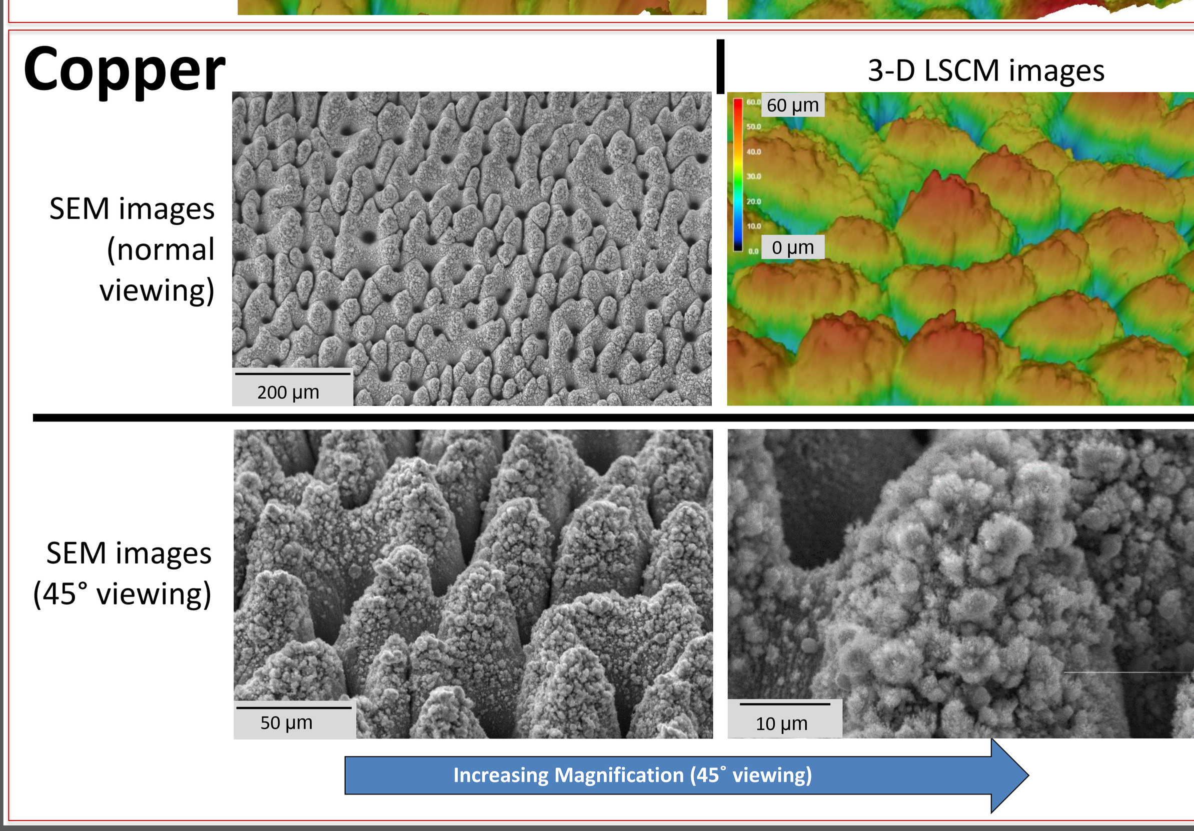
Zircaloy 4



4H-SiC



Copper



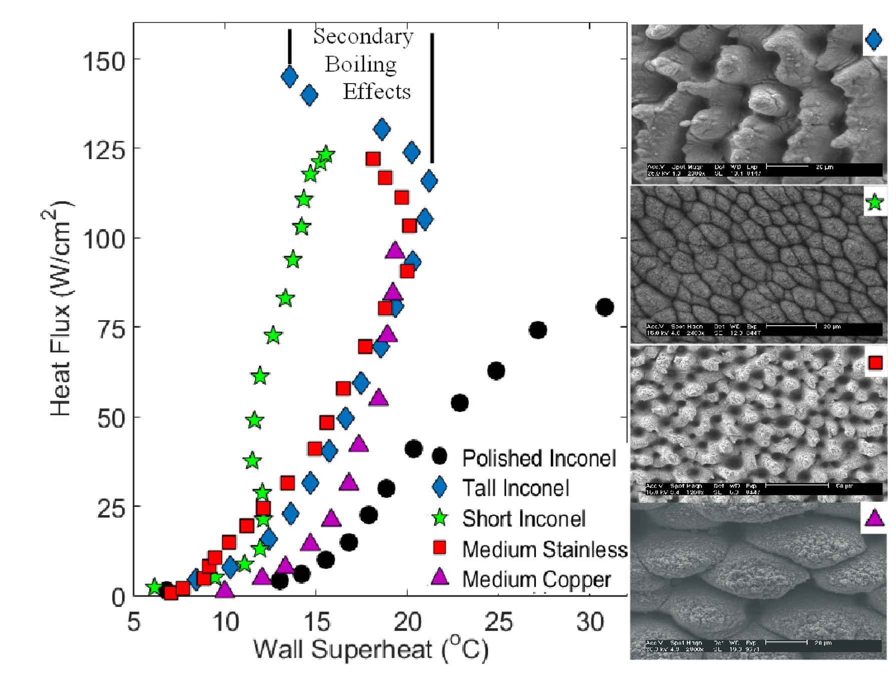
Sample	Design parameters: Peak fluence (J/cm²)	Pulse count (pulse/area)
Inconel 740H		
NC-pyramids	0.16	21,277
BSG-mounds	2.93	1,174
ASG-mounds	20.83	165
Zircaloy 4		
NC-pyramids	0.36	9,562
BSG-mounds	2.74	1,256
ASG-mounds	17.7	194
4H-SiC		
NC-pyramids	0.77	19,363
BSG-mounds	0.89	1,721
Pits	2.26	1,019
Copper		
Mounds	18.0	980

Measured Parameters of FLSP Structures

Sample	Average roughness (µm)	Average structure height (µm)	Maximum structure height (max peak to max valley) (µm)	Surface area ratio (measured surface area/geometric area)
Inconel 740H				
NC-pyramids	11.7	54.2	76.7	3.2
BSG-mounds	2.7	15.3	30.1	4.3
ASG-mounds	15.7	77.4	85.7	7.0
Zircaloy 4				
NC-pyramids	12.0	62.6	93.6	5.2
BSG-mounds	3.1	19.2	25.7	2.8
ASG-mounds	11.2	54.7	83.8	5.1
4H-SiC n-type				
NC-pyramids	50.0	208.2	241.2	5.9
BSG-mounds	2.0	8.5	12.2	3.6
Pits	3.0	11.8	16.8	2.0
Copper				
Mounds	6.8	42.1	61.7	3.7

Physical parameters measured using Keyence laser scanning confocal microscope (LSCM)

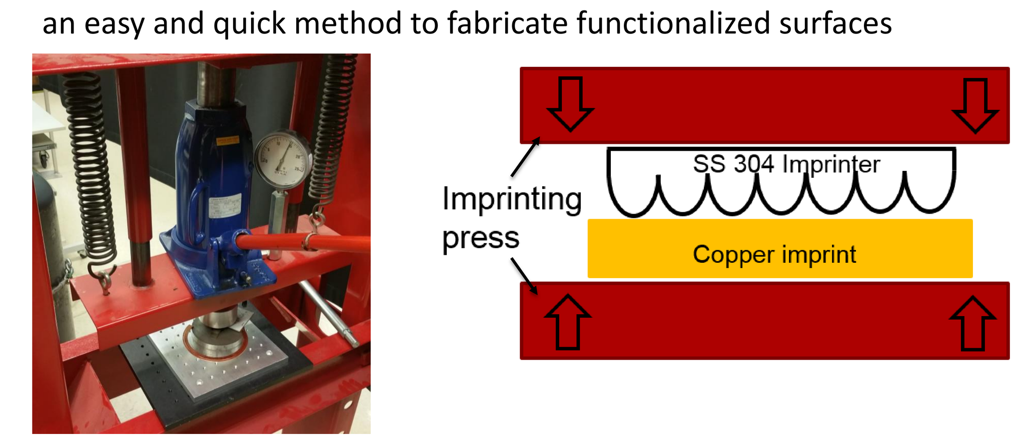
Heat Transfer Enhancement of FLSP Structures

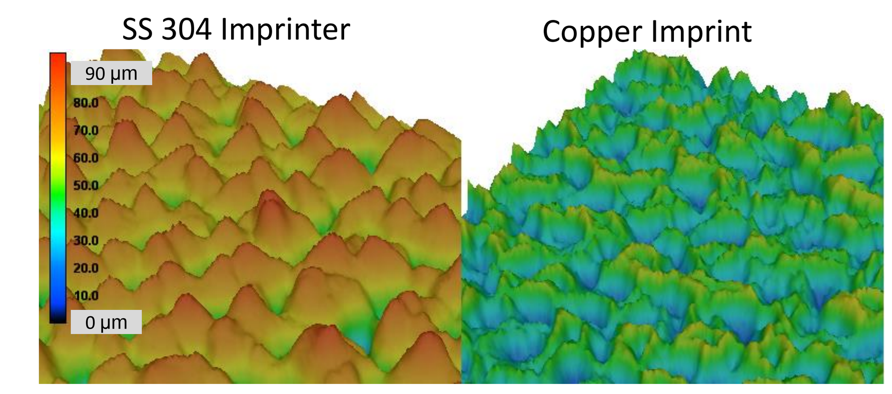


Imprinting Copper with Inverse FLSP Structures

Goal: To imprint reverse FLSP structures on copper using mechanical press as a method to scale FLSP to larger areas

- Preliminary work has shown potential that imprinting FLSP structures is an easy and quick method to fabricate functionalized surfaces





Conclusions

With the novel method used in this project, femtosecond lasers can be used to create unique micro and nanostructures on a variety of materials.

1. Through this project insight was gained into how certain morphologies form and how to control their formation on materials important for heat transfer applications
2. FLSP is not restricted to metals but can be produced on a variety of materials
3. FLSP structures have shown an increase the both heat transfer coefficient and critical heat flux with respect to similar polished samples

Acknowledgements

This work is funded through a grant by the Nebraska Center for Energy Sciences Research (NCESR), Office of Naval Research (ONR), and NASA Experimental Program to Stimulate Competitive Research (EPSCoR).

University of Nebraska Lincoln
NEBRASKA CENTER FOR ENERGY SCIENCES RESEARCH