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Direct Nanoparticle Printing of CL-20 Using Ultrafast Laser Irradiation

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Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Abstract

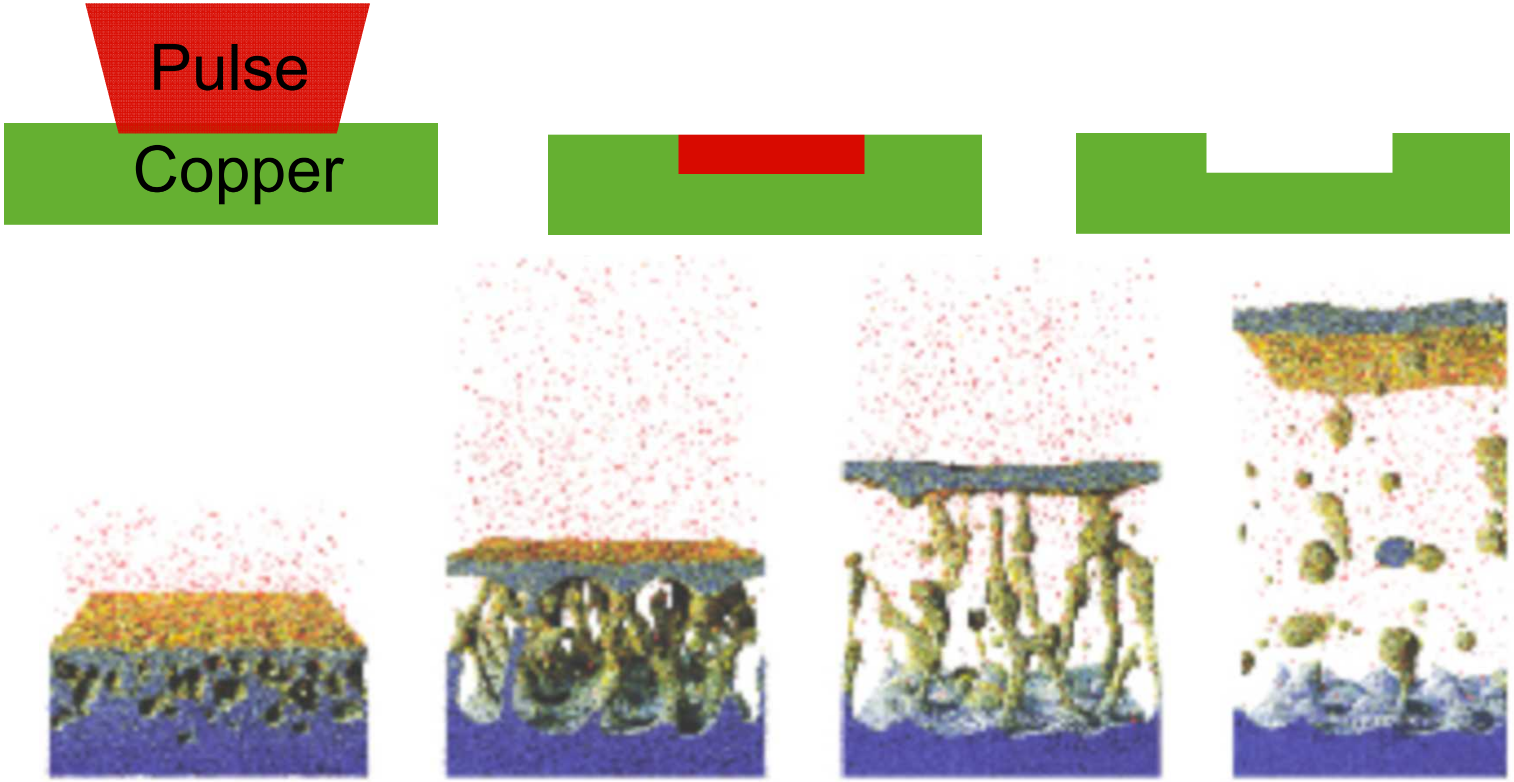
We have applied a nanoparticle laser-printing technique to energetic materials using CL-20 film lift-off from glass substrates after ultrafast (~50 fs pulse length) irradiation in air. Unique interactions of ultrafast laser pulses with the thin film energetic material allow for the deposition of micron-scale and nanoparticles onto glass substrates. Control over printed particles, such as the printed distribution, is achieved by changing the laser fluence and film-substrate distance. We demonstrate 2.8 μm CL-20 film removal from substrates resulting in rapid particle printing in air. Particles are printed and then characterized using optical and electron microscopy. Future work will also be discussed.

Outline

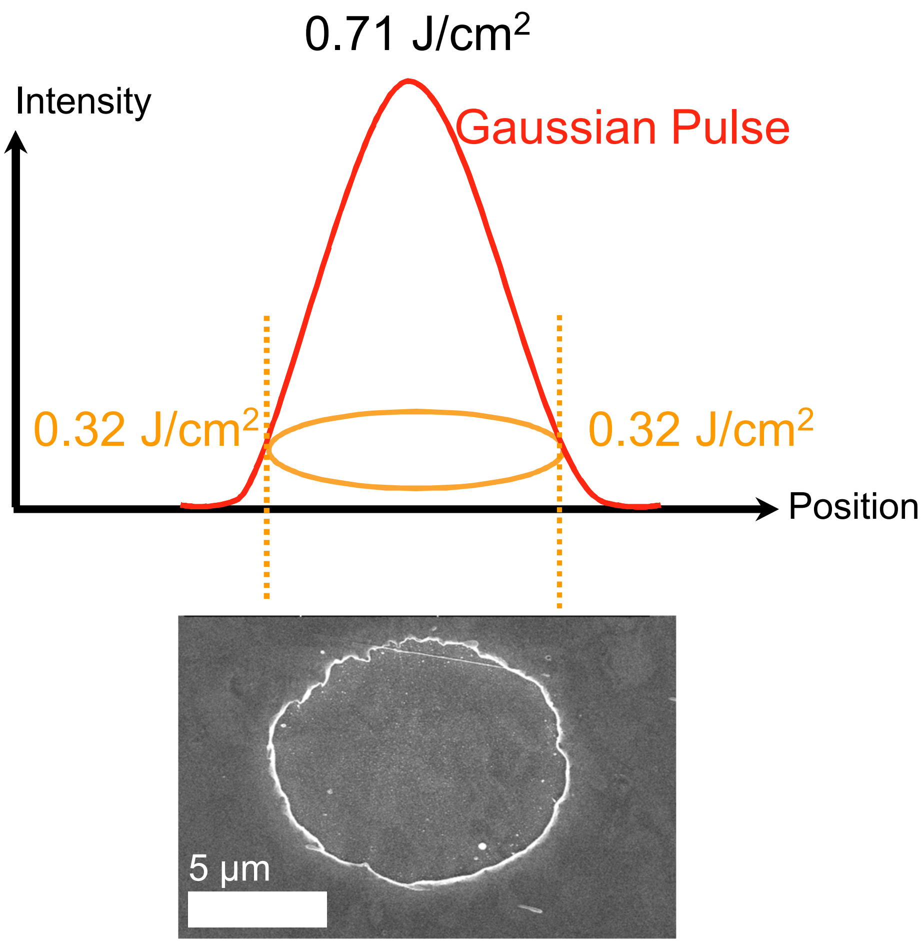
- Background work performed by Ryan Murphy
- Current Setup in the Explosives Component Facility
- Experimental Setup
- Results
- Future Work

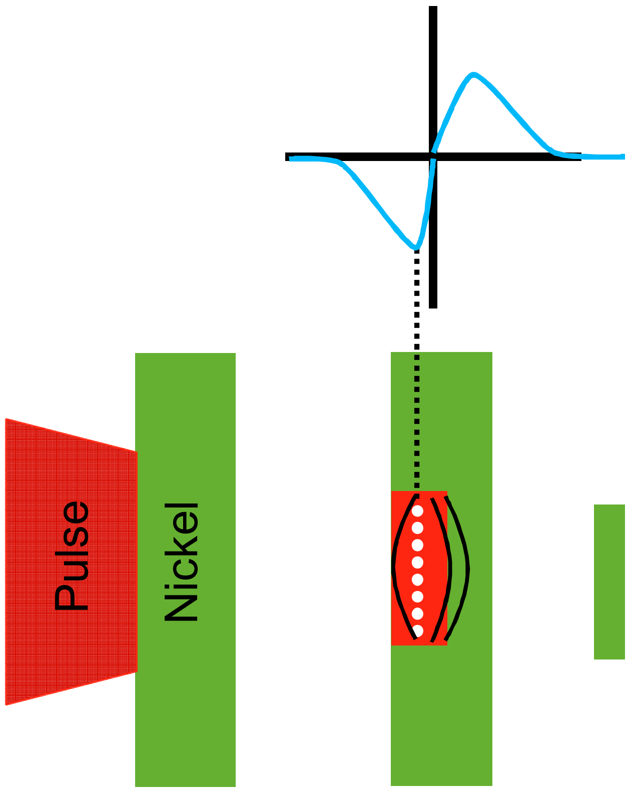
Ultrafast Laser Damage in Bulk Materials

- First few nanometers of material melts in ~ 3 ps.
- Rapid expansion leads to homogeneous void nucleation within melt.
- Material “breaks” where voids nucleate.

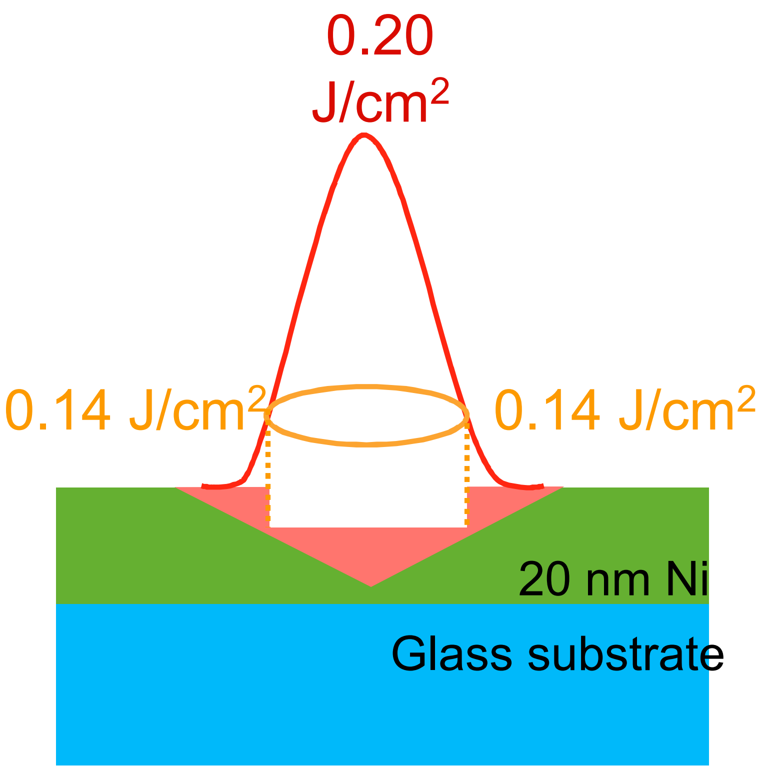


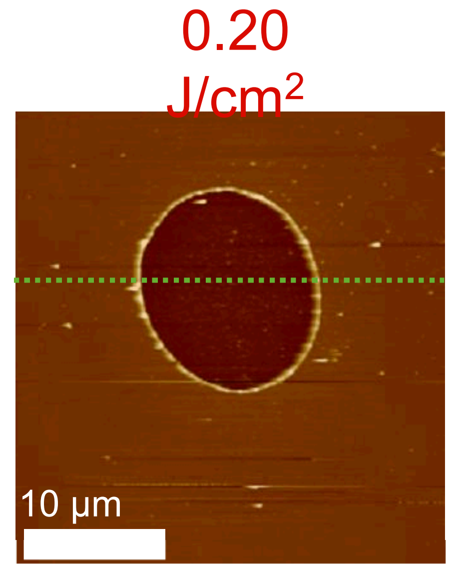
Deterministic Thresholds

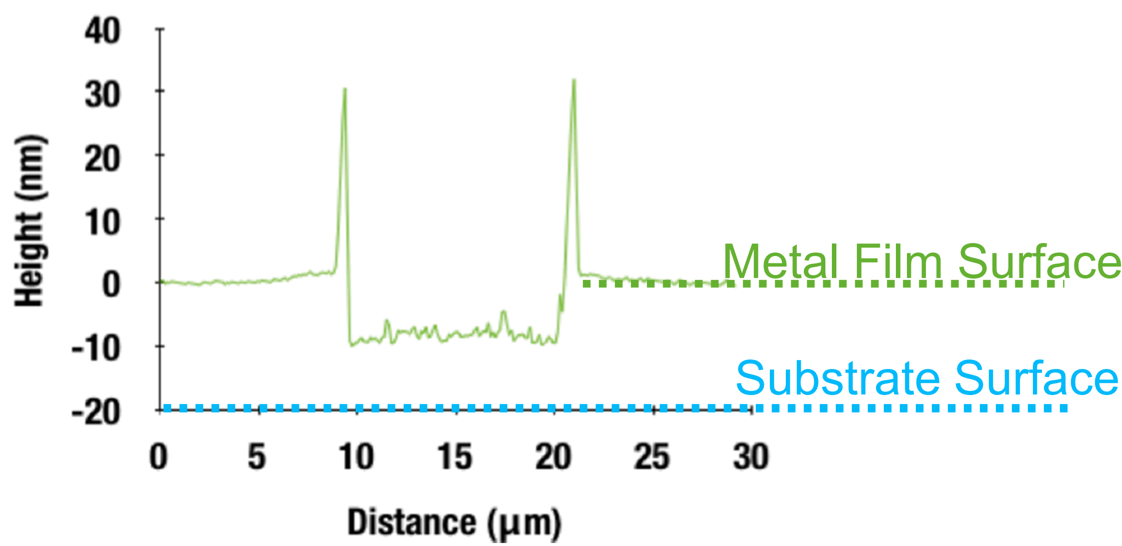




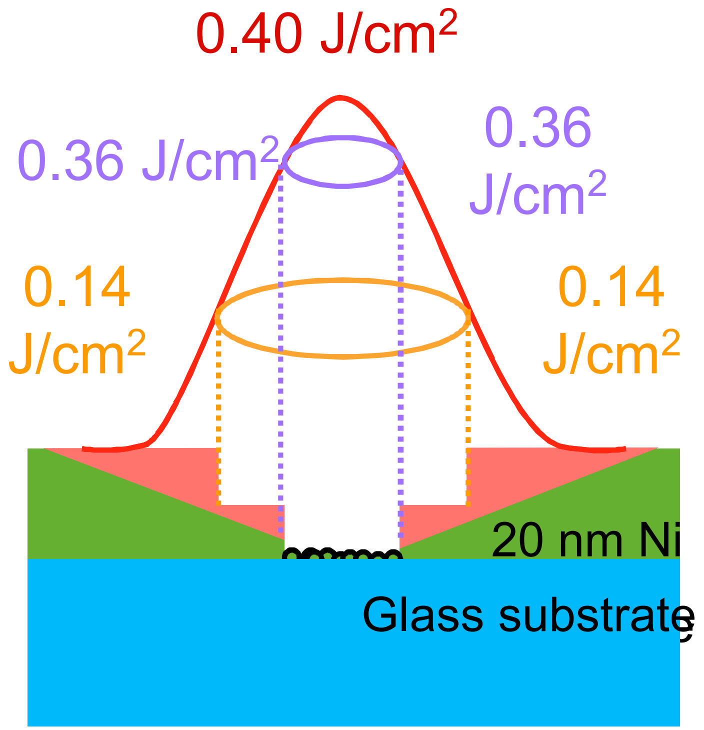
Low Fluence Removal Within Film

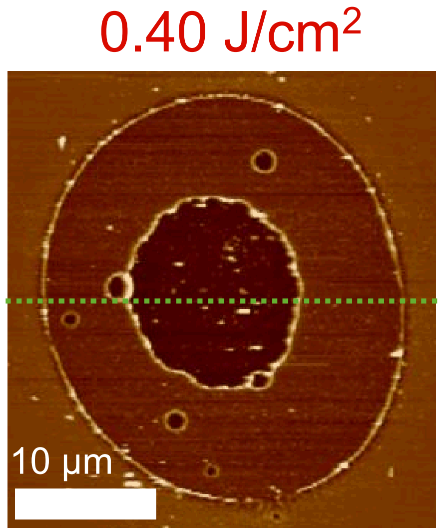


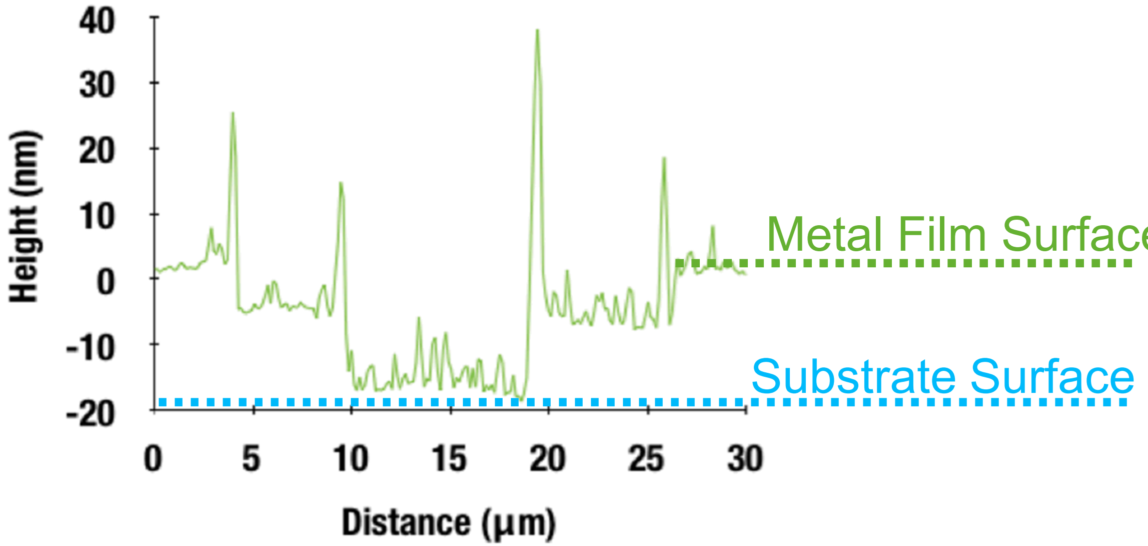




High Fluence Removal Within Film + at Interface

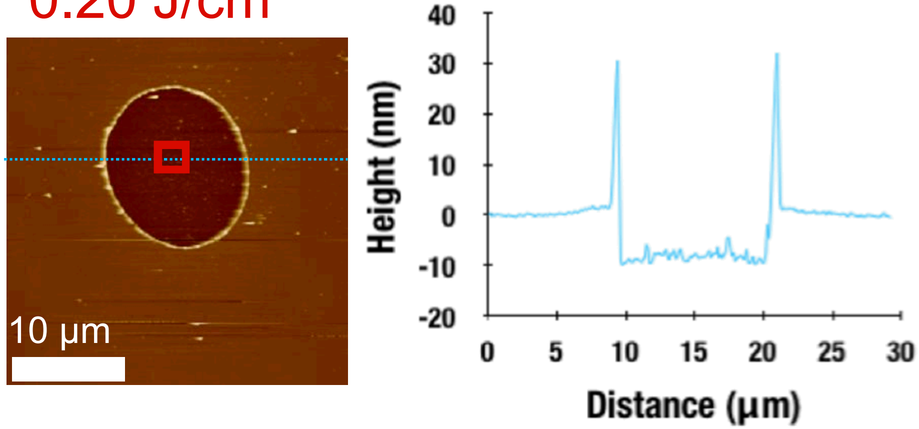




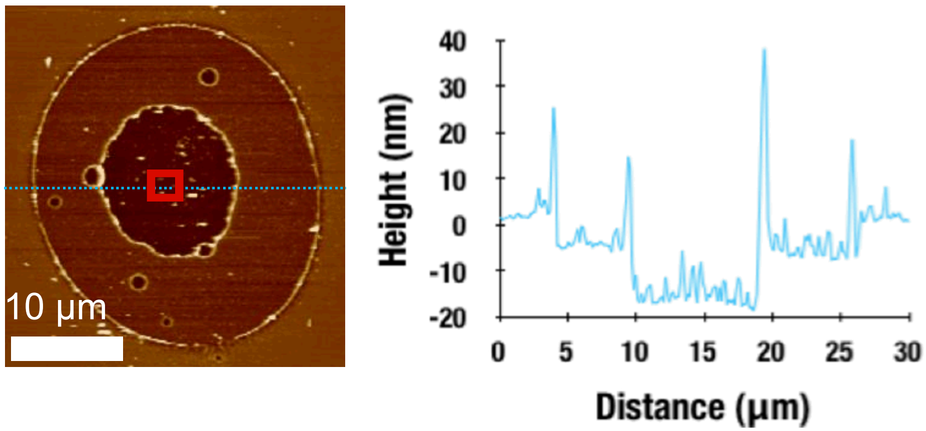


Void Nucleation Controls Surface Roughness

0.20 J/cm^2

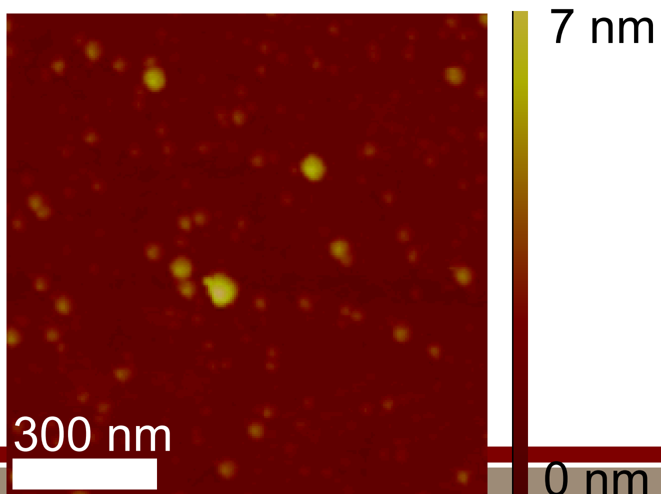


0.40 J/cm^2



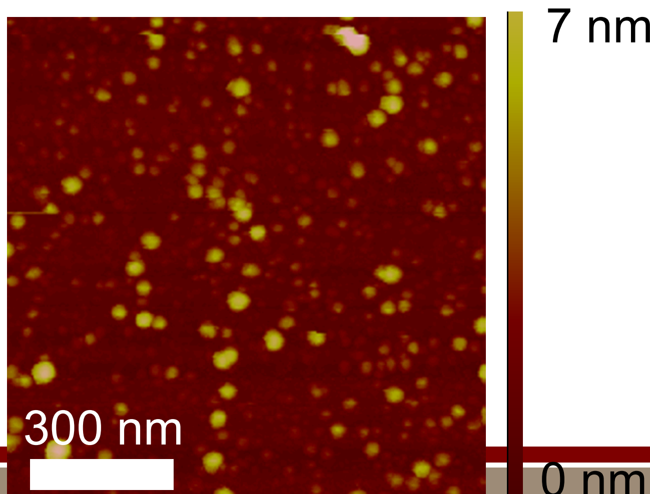
<u>Intra-film Separation</u>

RMS Roughness = 1.27 nm

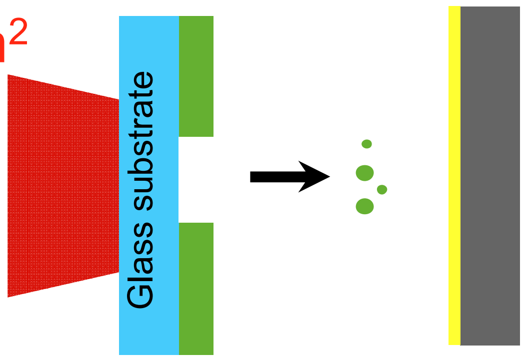


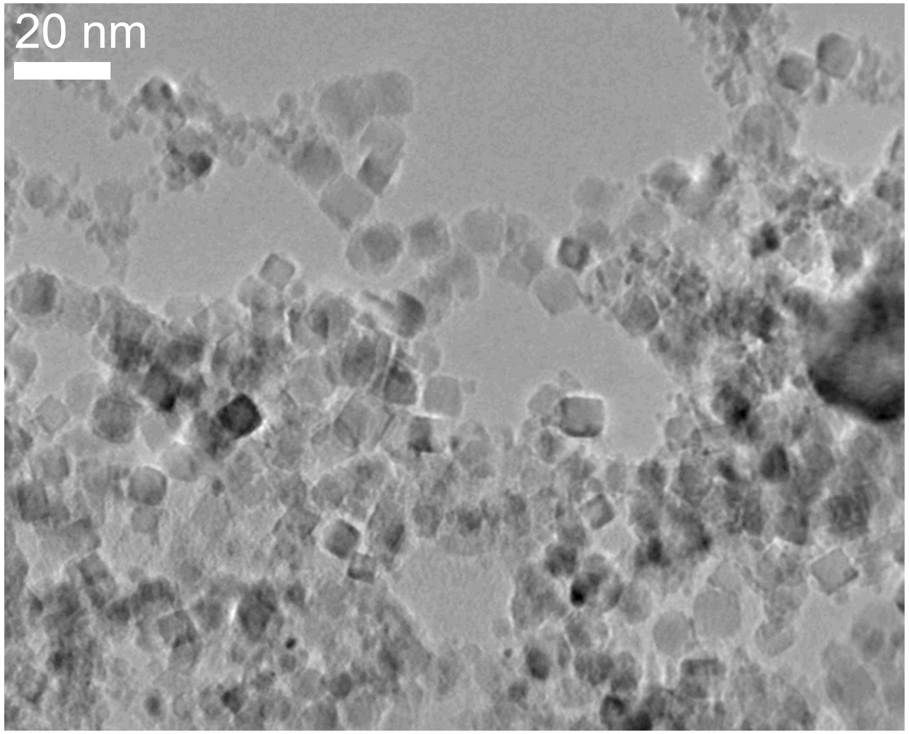
<u>Interface Separation</u>

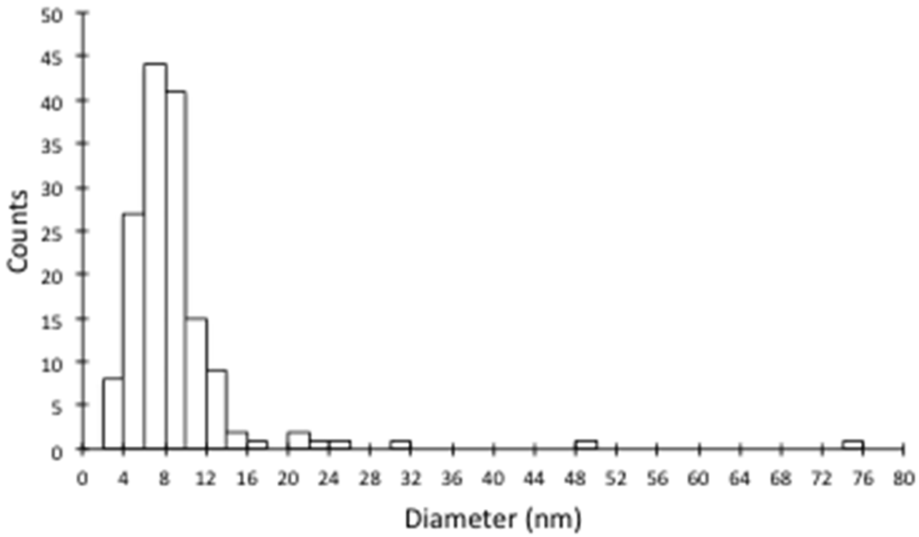
RMS Roughness = 3.06 nm



Ni Nanoparticle Printing



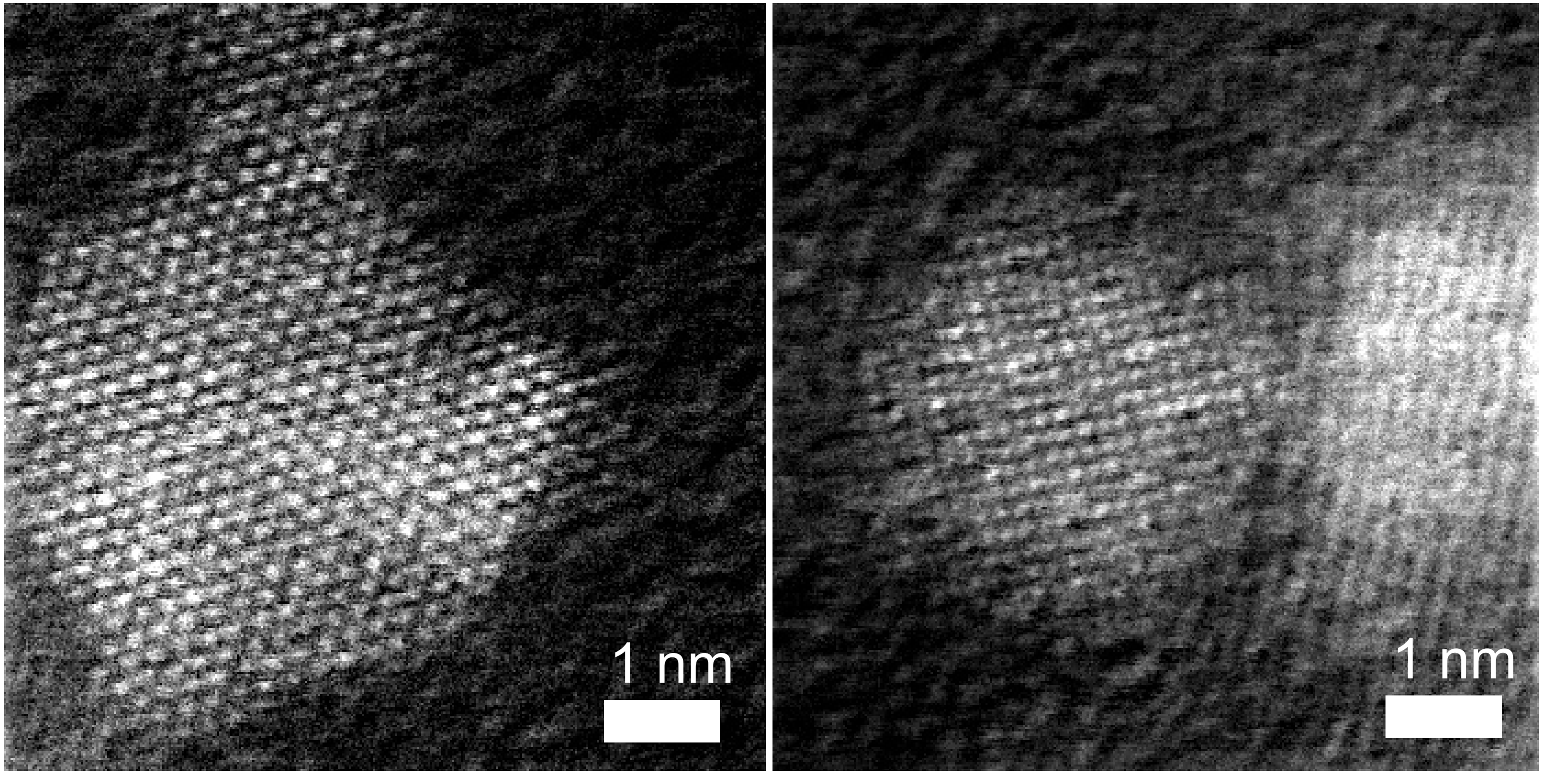




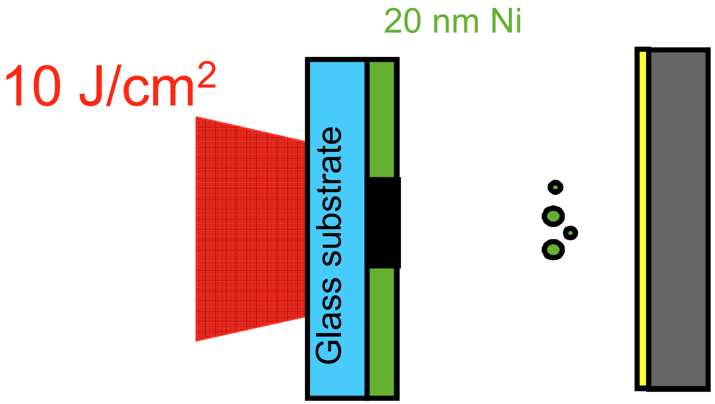
- Can we pattern surfaces with energetic materials using laser ablation?

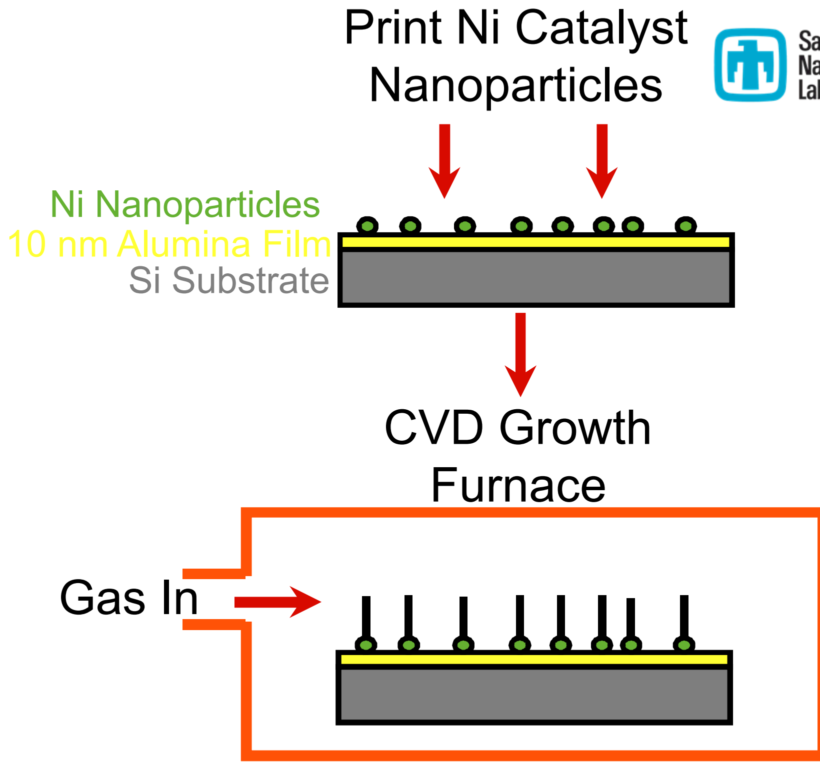
Faceted Nanoparticles

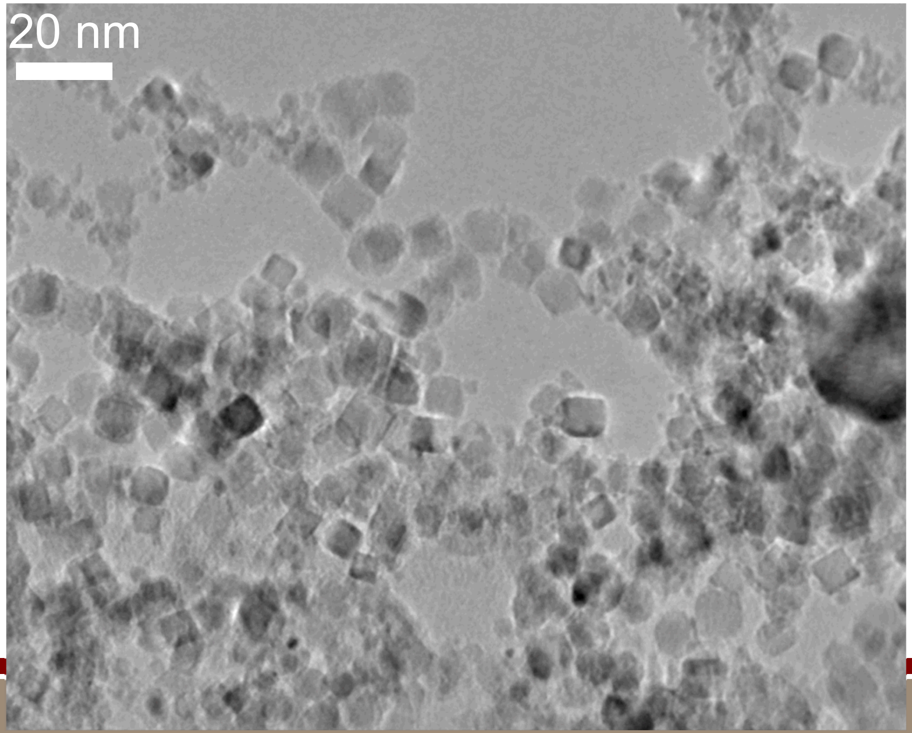
Atomic Resolution

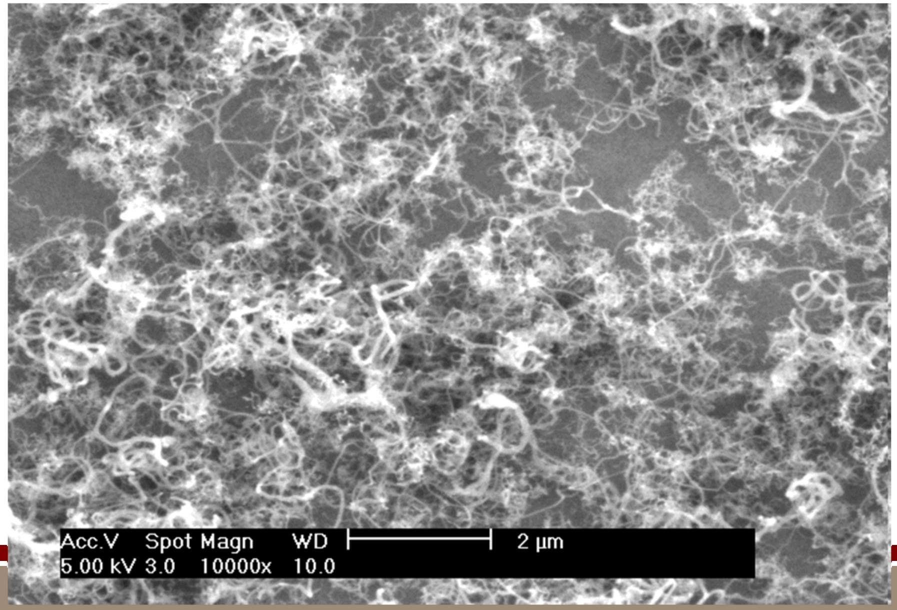


Ni Nanoparticle Printing

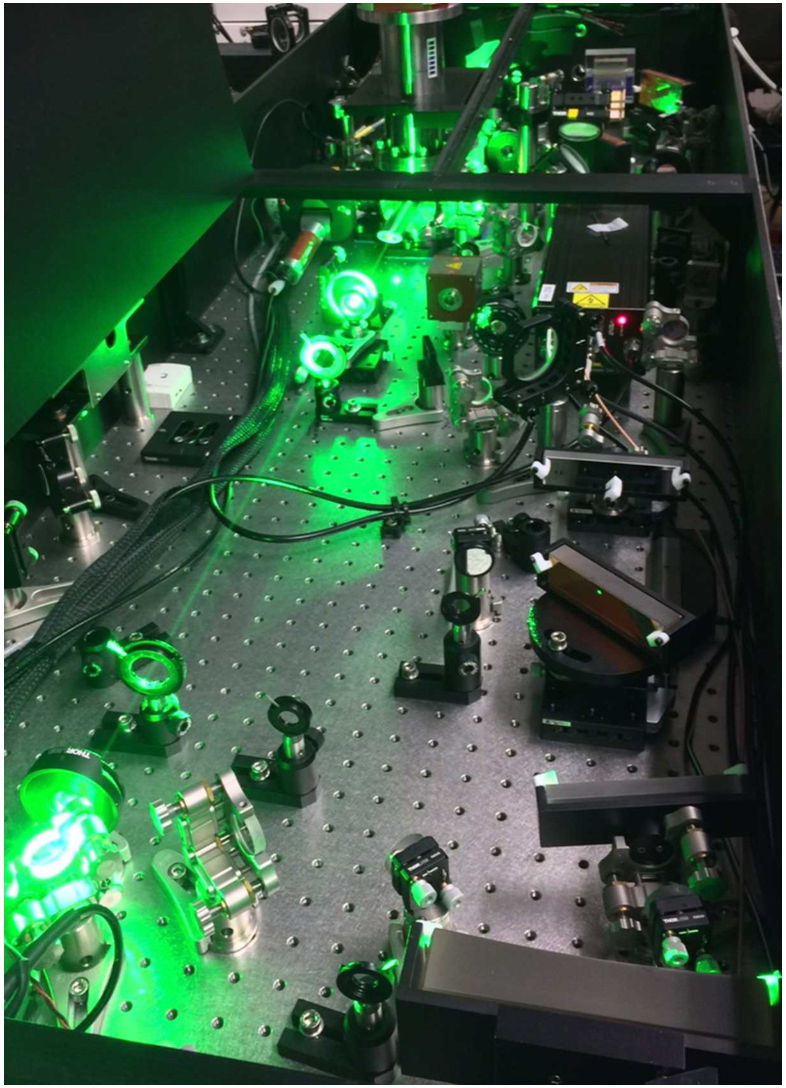


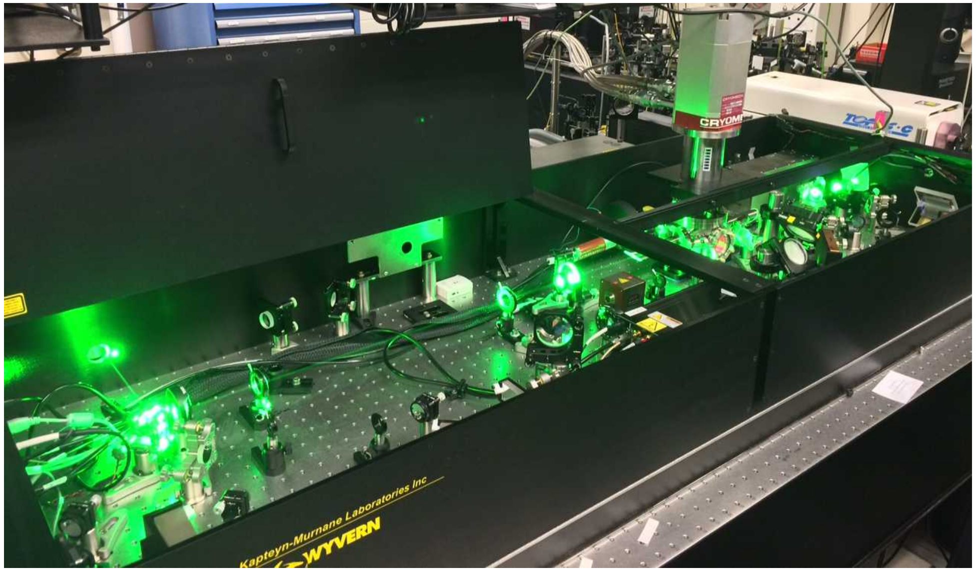






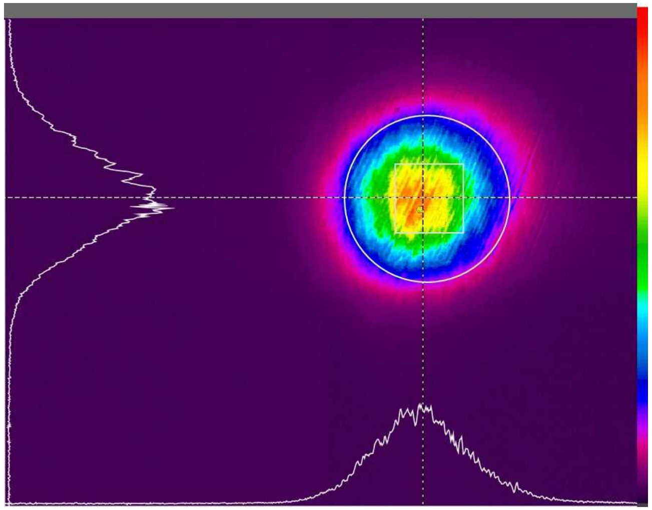
Laser Setup ECF



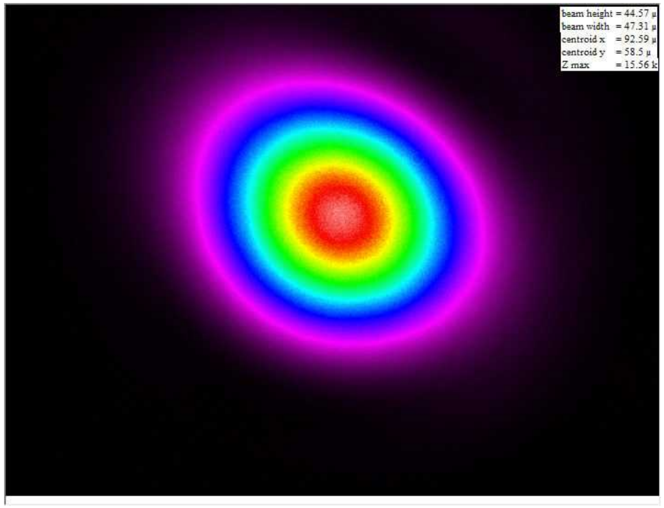


Laser Parameters
4 mJ
1 kHz (Single shot capable)
40 fs pulse width
35 nm bandwidth
785 nm center wavelength

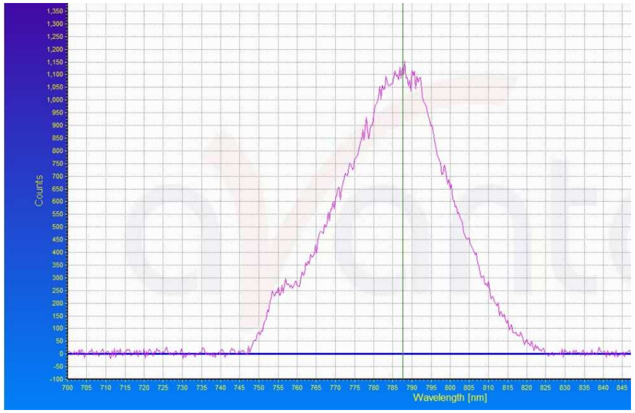
Laser Setup Diagnostics



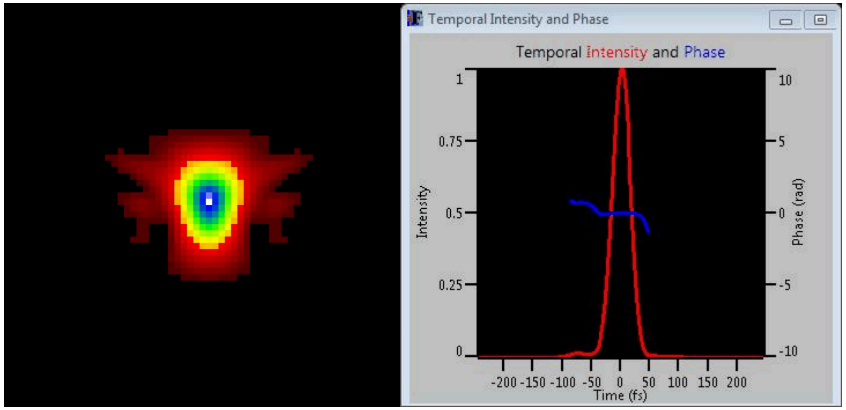
Nearfield Camera



Farfield Camera

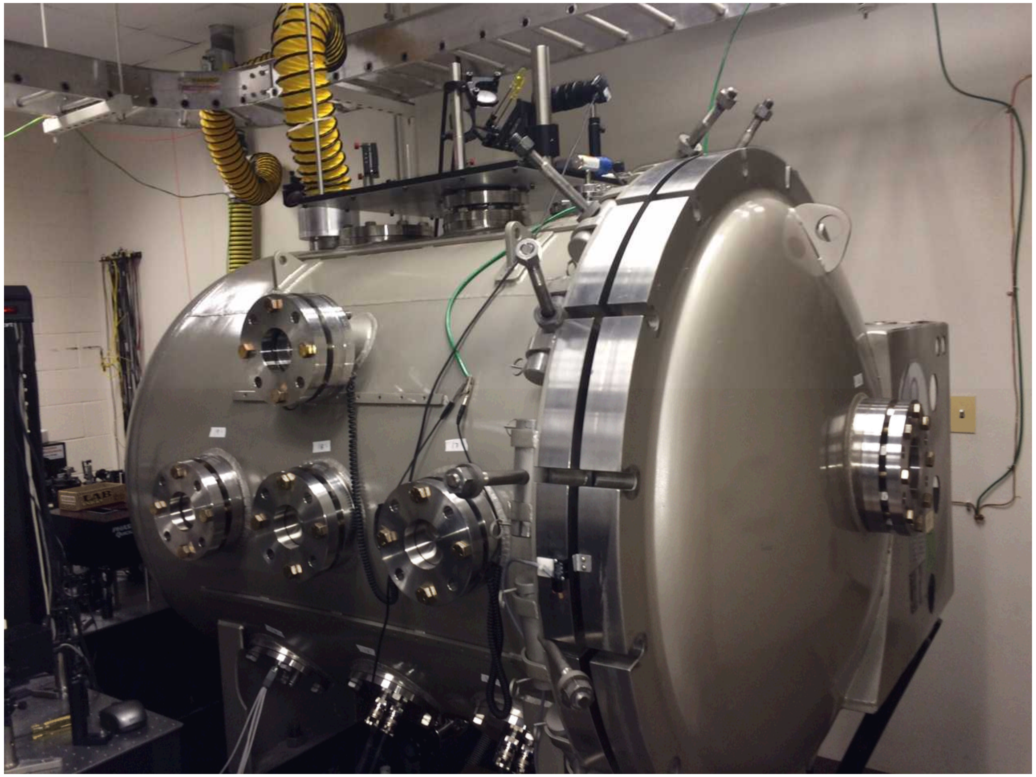


Spectrometer

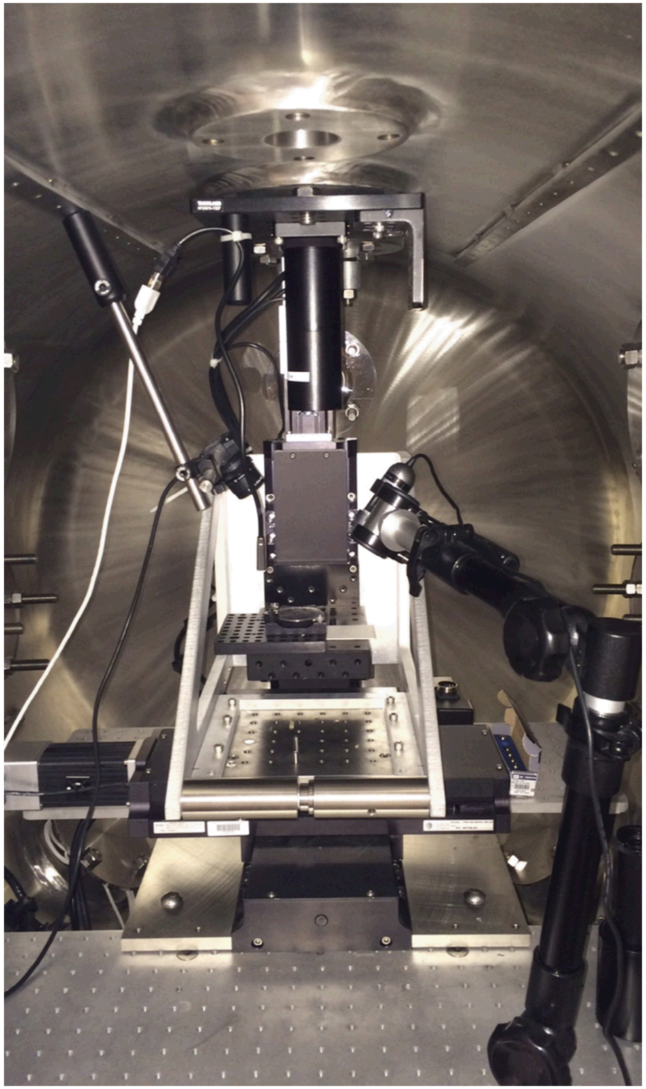


FROG

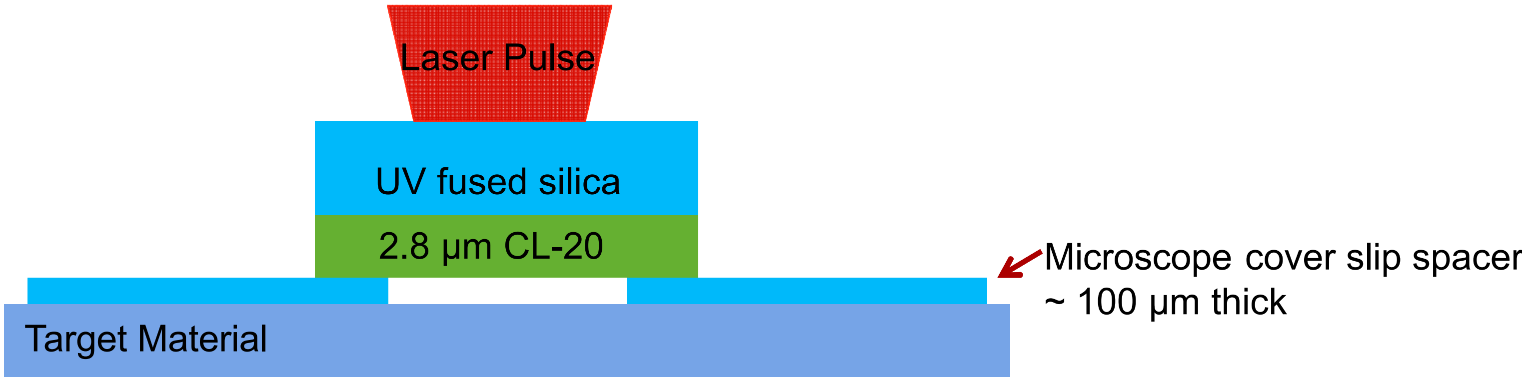
Experimental Setup

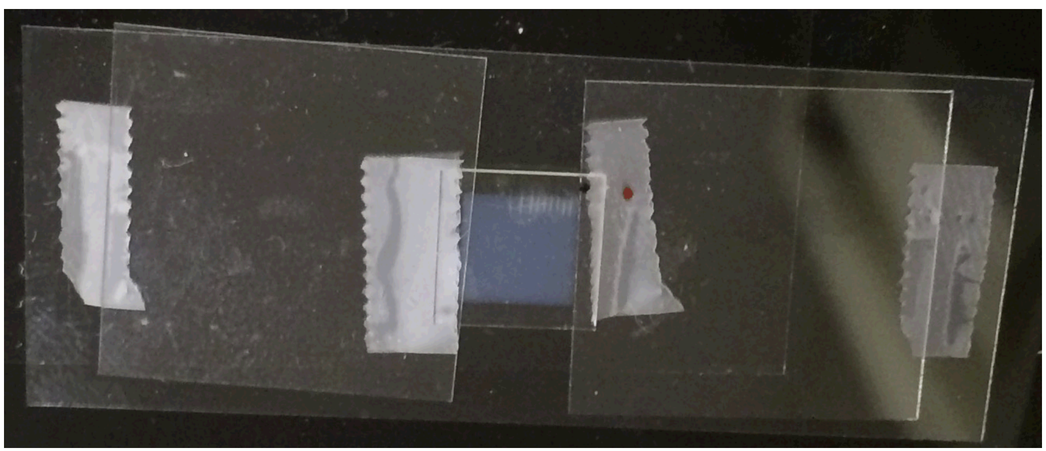


Explosives chamber
10g TNT equivalent capacity
Vacuum chamber and full venting
Aerotech 3-D computer controlled stage
3 cameras for remote viewing



Experimental Setup- Samples

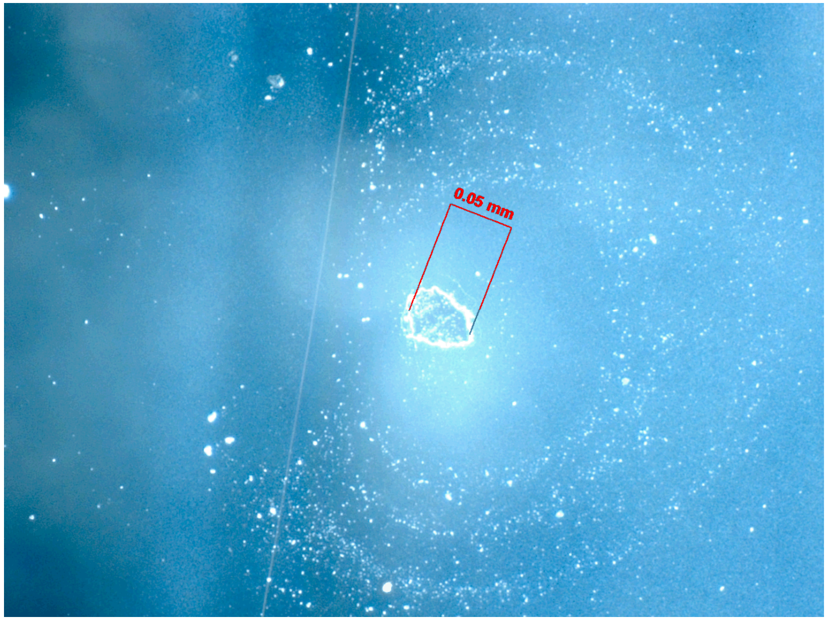


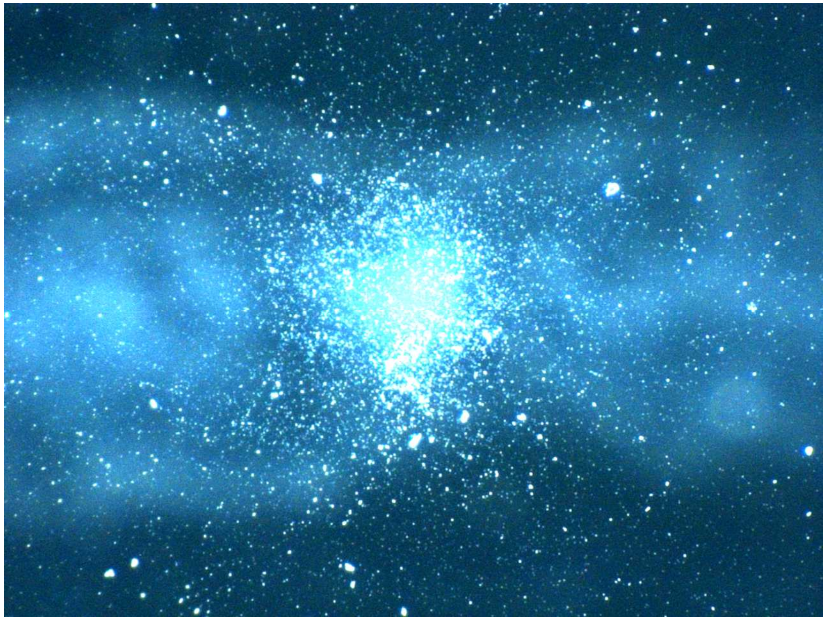


Data Set

- Thin film CL-20 sample (2.8 µm)
- Focusing optic – 200 mm fl lens (~ 20µm spot size)
- Spacer distance ~ 100 µm cover slip spacer
- Pulse width ~ 40 fs –close to transform limited
- Five energy levels
  - 160 µJ (damaged the target), 80 µJ, 40µJ, 20 µJ, 15µJ (ablation threshold)

Results 80 uJ – Optical Microscope

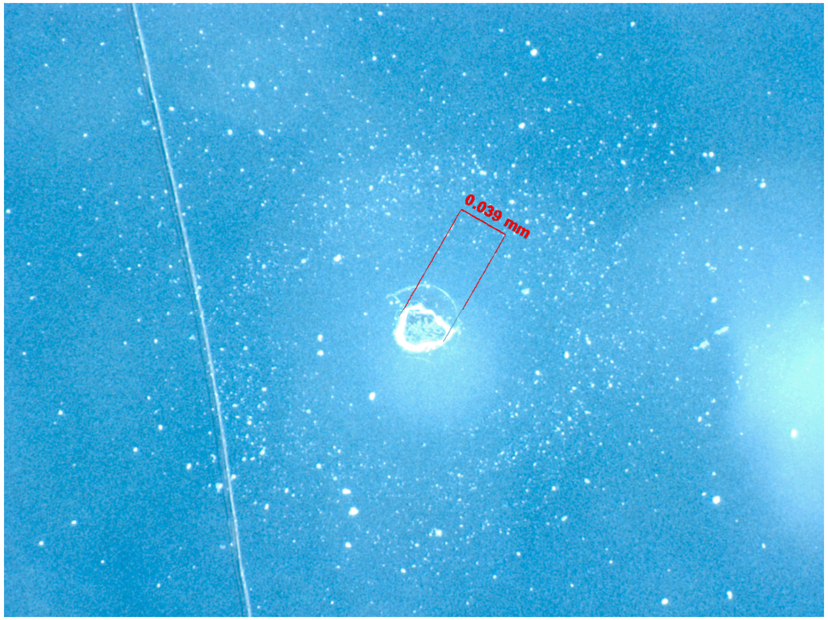


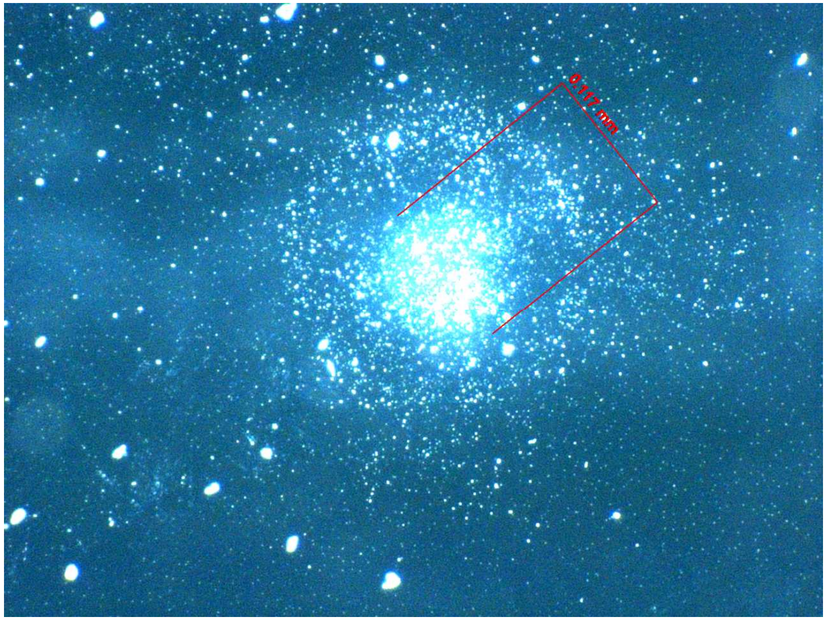


Laser spot profile on CL-20 film
50 μm film spot

Printed CL-20 particles
~100 μm particle distribution

Results 40 uJ – Optical Microscope





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40 μm film spot

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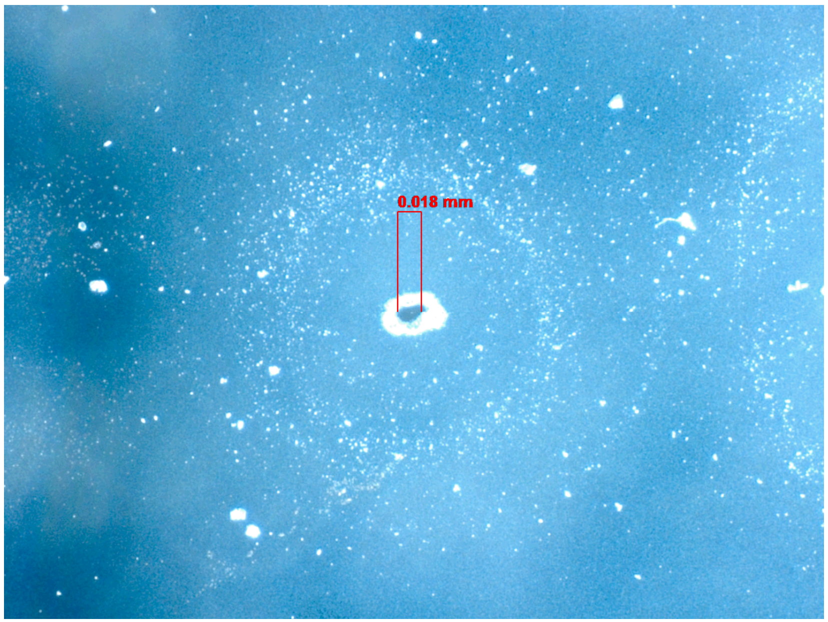
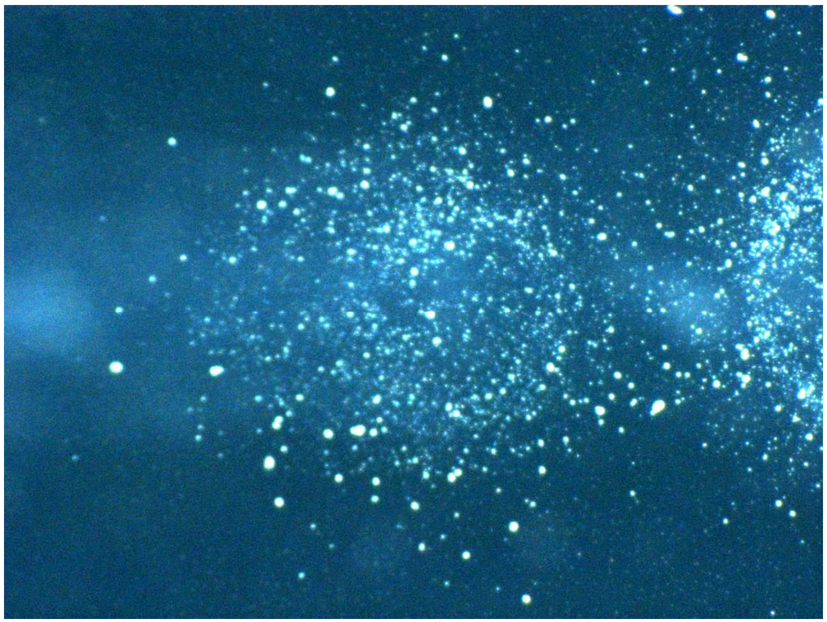
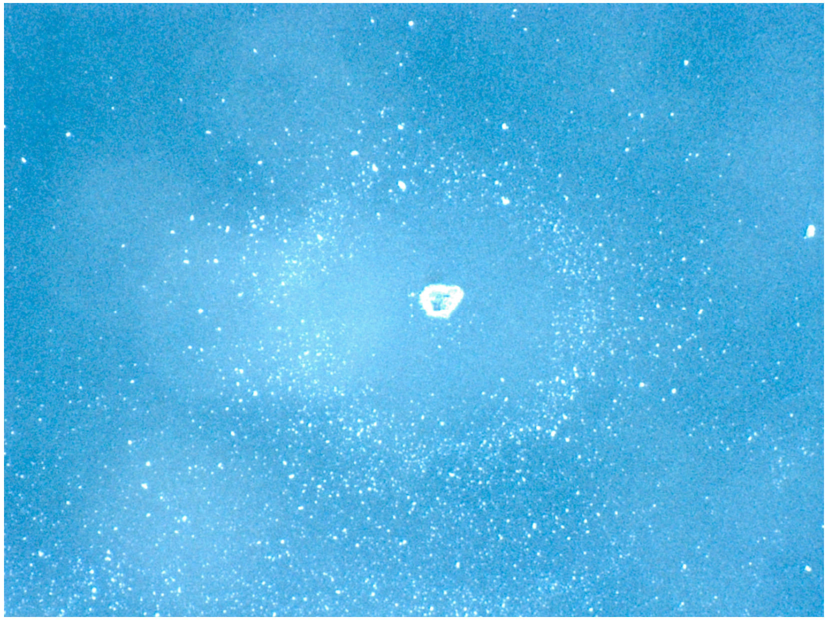


Laser spot profile on CL-20 film
18 µm film spot

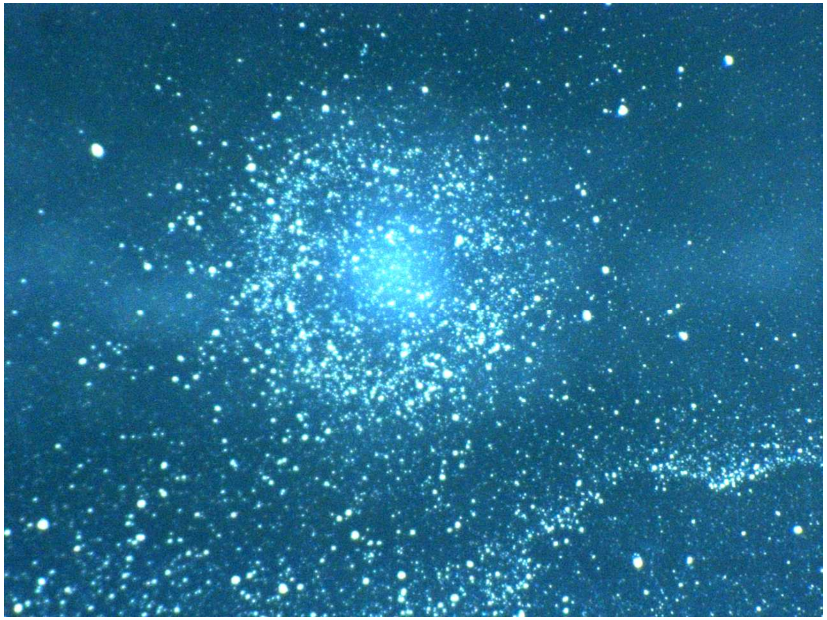


Printed CL-20 particles
~70 µm particle distribution

Results 15 uJ – Optical Microscope

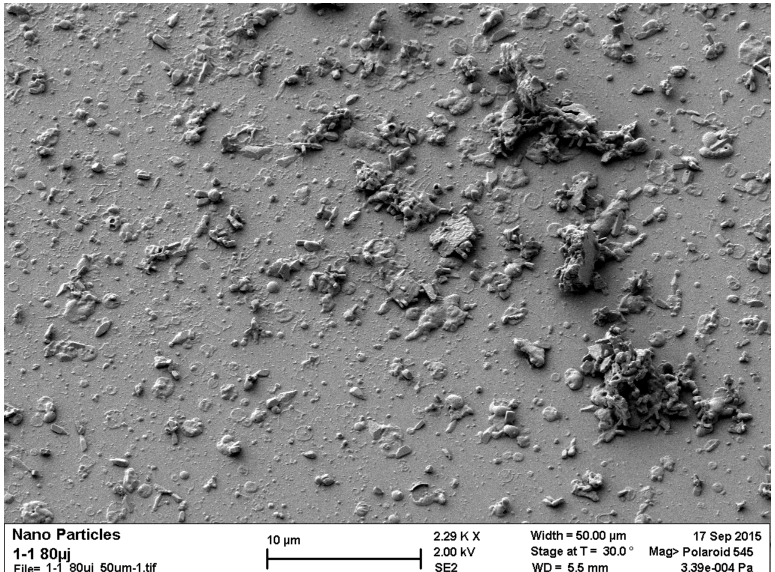


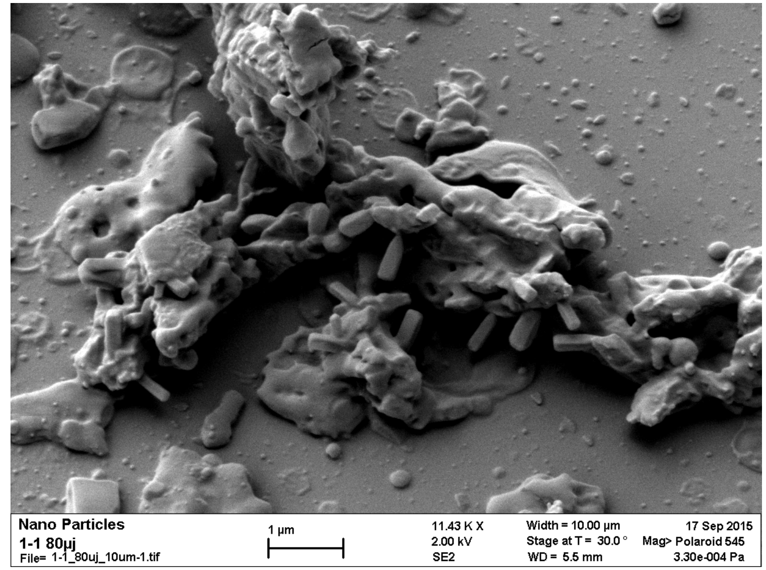
Laser spot profile on CL-20 film
17 µm film spot size

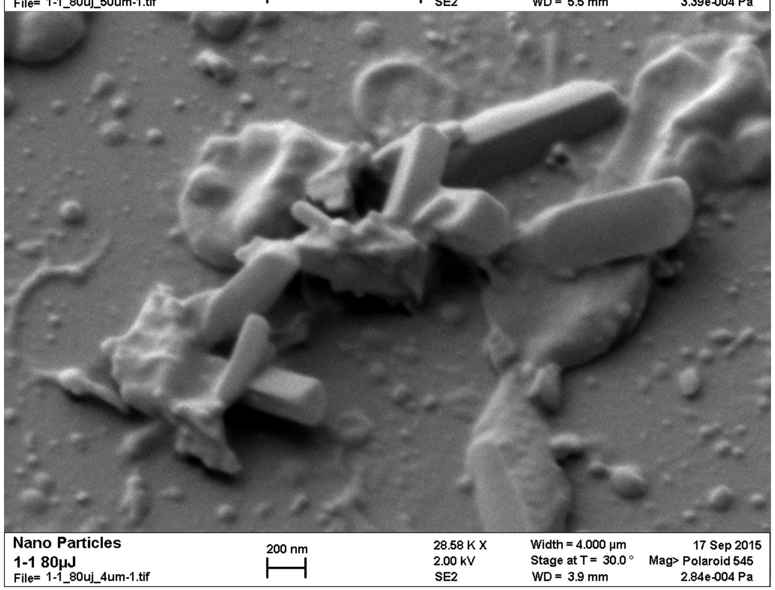


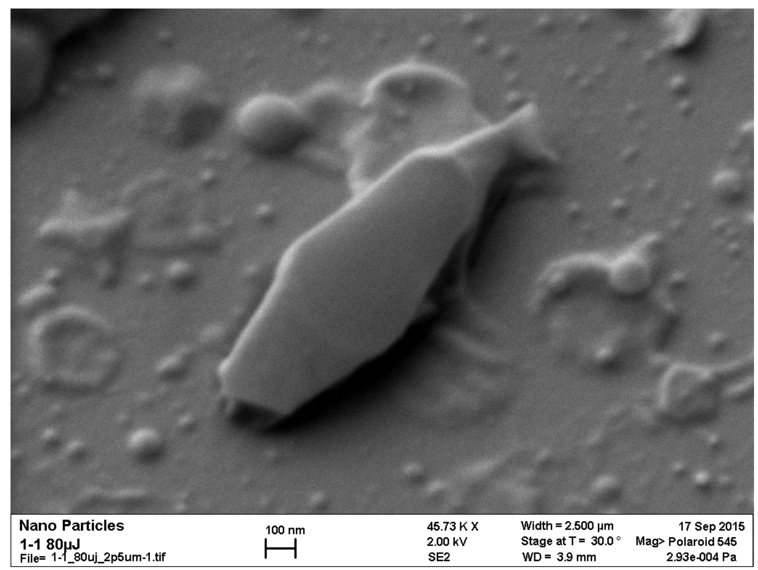
Printed CL-20 particles
~70 µm particle distrubution

Results 80 uJ – SEM

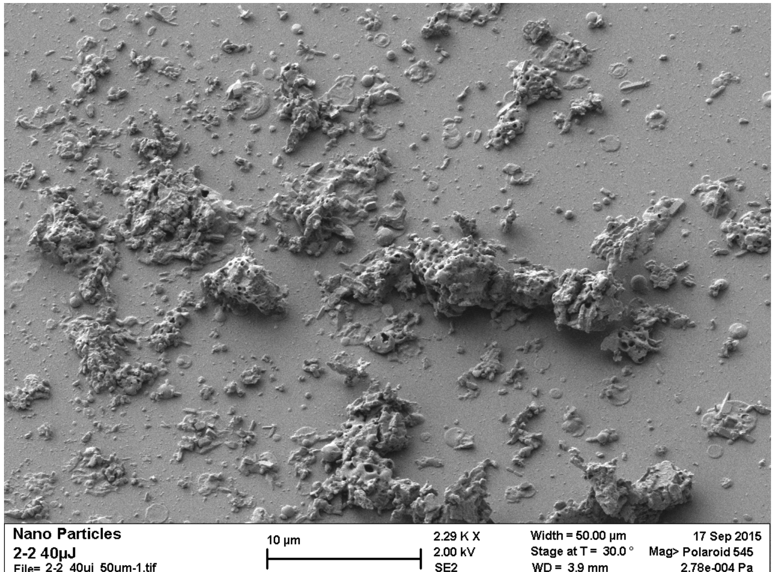


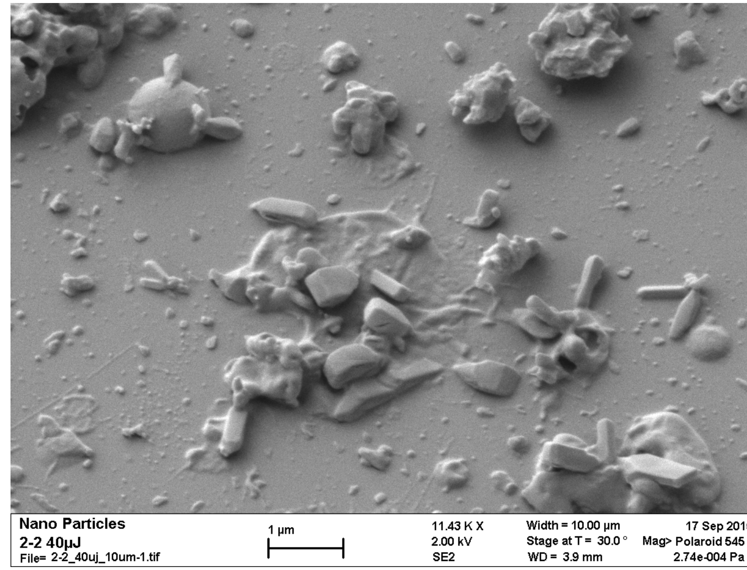


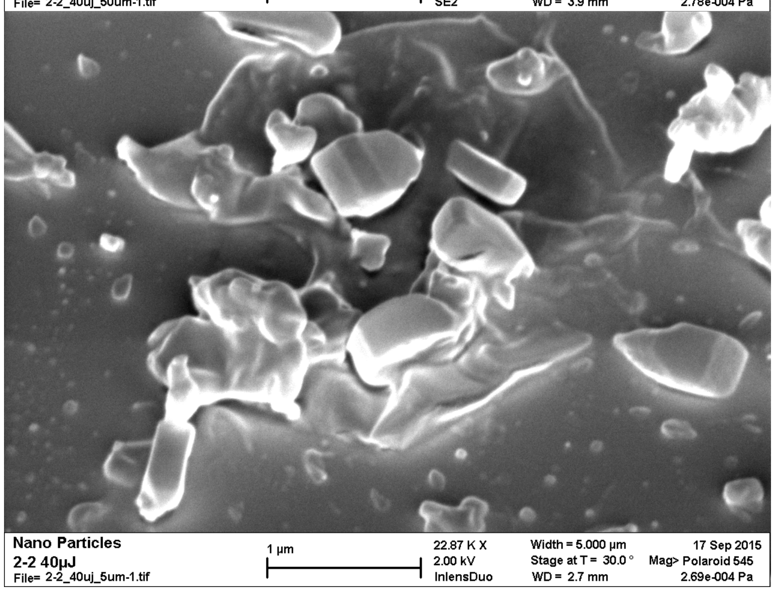


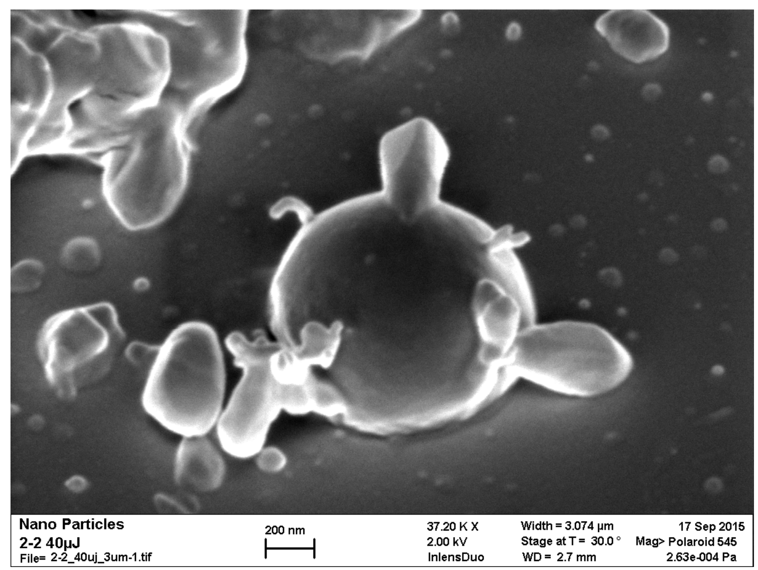


Results 40 uJ – SEM

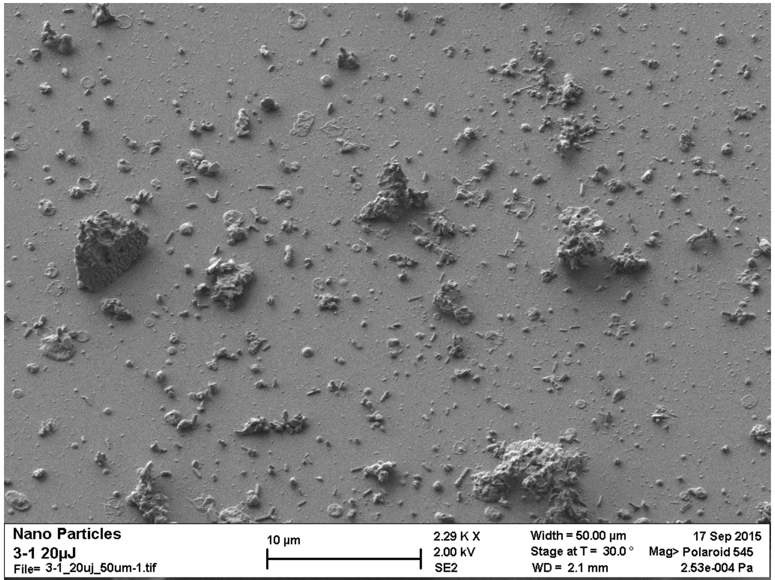


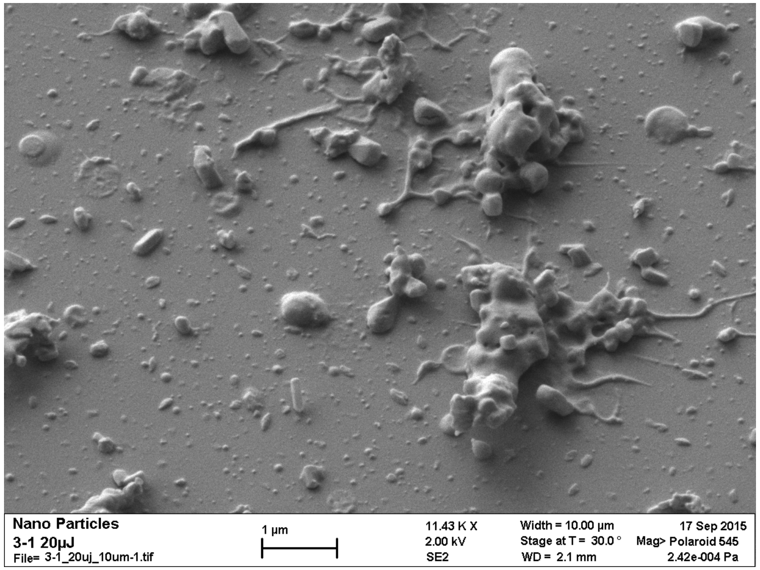


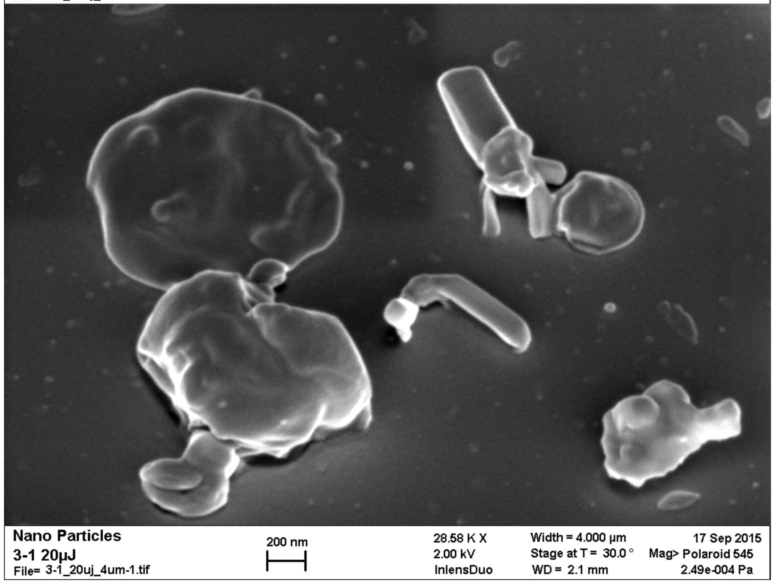


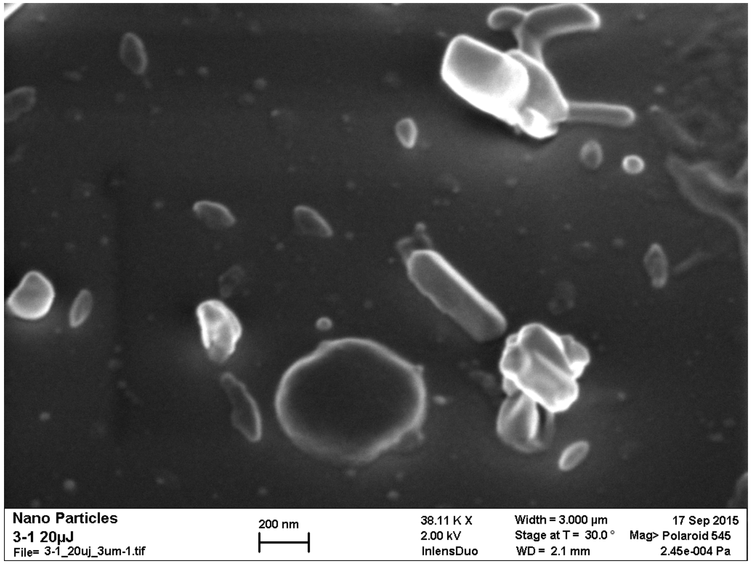


Results 20 uJ – SEM

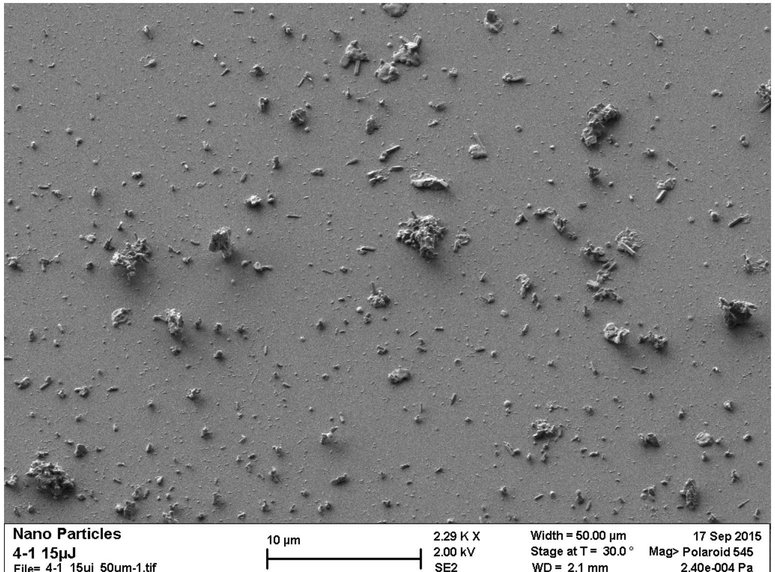


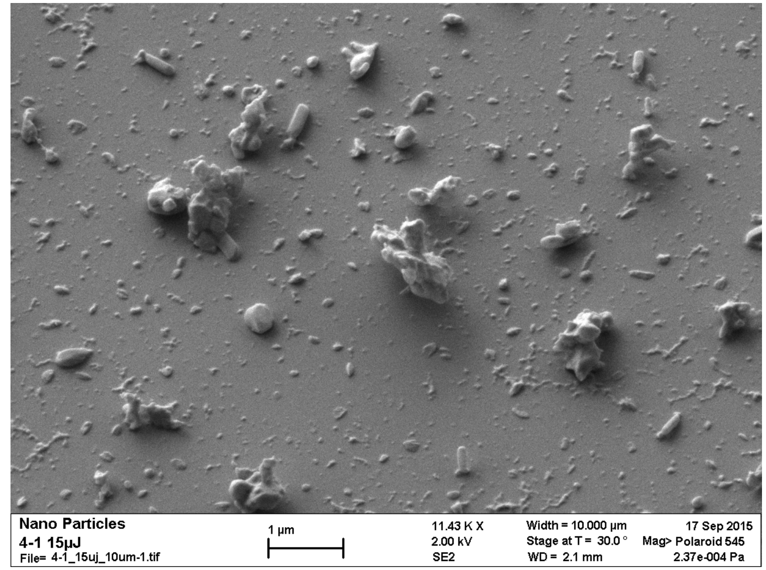


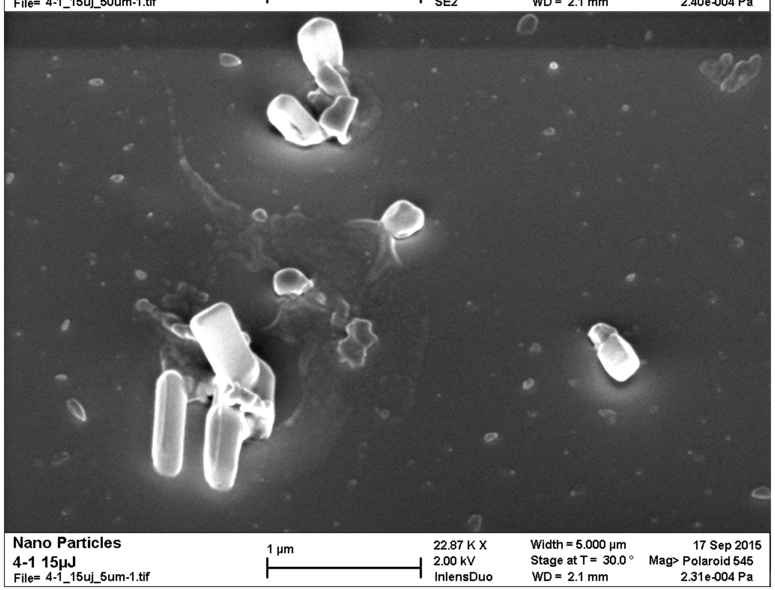


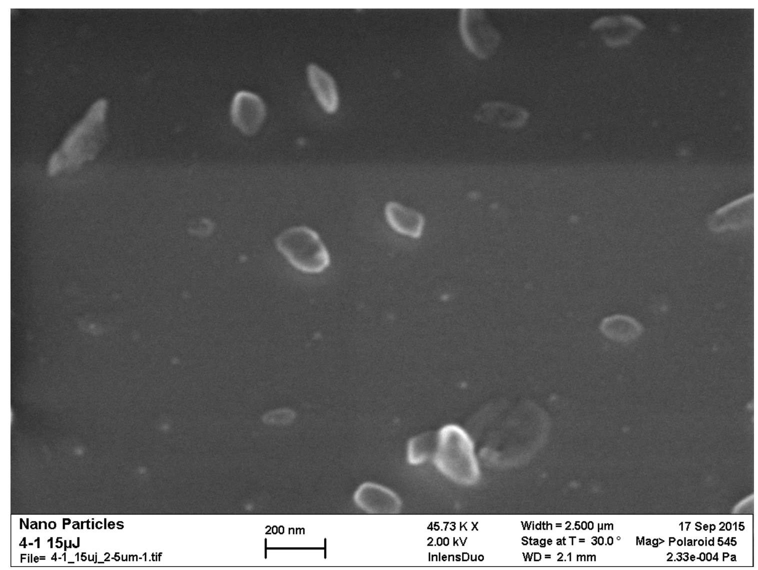


Results 15 uJ – SEM









Results- Discussion

- Too high energy damages the target material
- High fluence appears to give larger particle agglomeration
- Generating particles close to the ablation threshold appears to give a more uniform particle size distribution

Future Work

- Changing film thickness has shown with other materials to influence nanoparticle size. We would like to investigate using multiple film thickness samples
- Stand off and focusing geometry both contribute to the macro deposited spot. Would like to investigate different geometries.
  - As part of this we would like to pursue printing different features including continuous lines
- All work was done at a fixed pulse width ~40 fs. Would like to investigate chirping the pulse
- All work was done at 785 nm. Other work shows more efficient ablation closer to the UV. Could frequency double the light.

Future Work - Cont

- Analysis was limited to optical microscope and SEM. We plan on doing TEM measurements to validate that no changes were made to the energetic material. X-ray diffraction measurements are also a possibility.