

Plasmonic metamaterials for high delta-V laser ablation propulsion in cislunar orbits

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Objectives

- Examine nanosecond laser ablation for future high delta-V propulsion and fast-transit maneuvering.

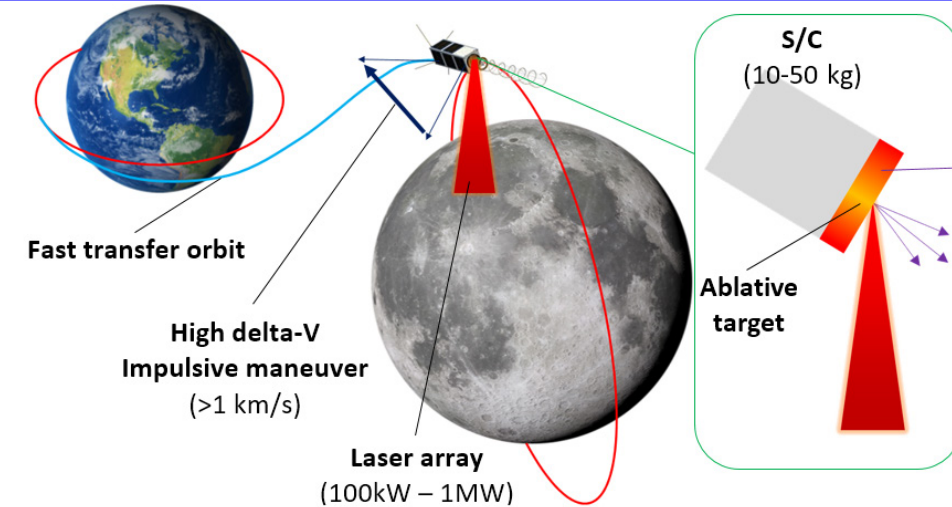
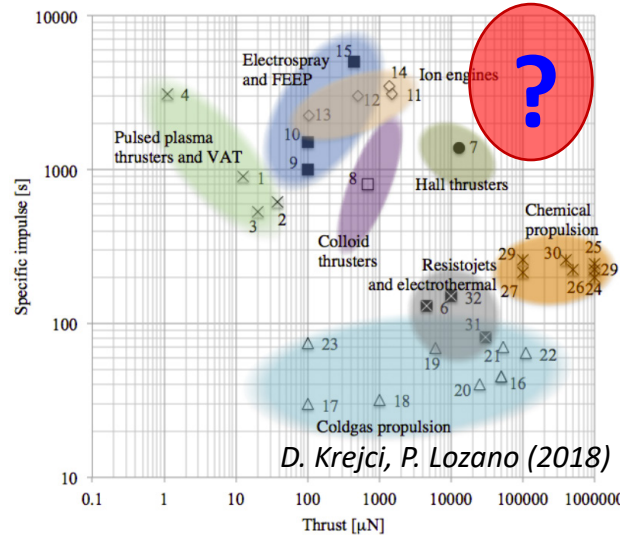
Science and technology gap

- Electric engines: efficient (high I_{sp}), but slow (low thrust)
- Chemical engines: fast (high thrust), but low I_{sp}
- Fast high- ΔV maneuvers are beyond the reach

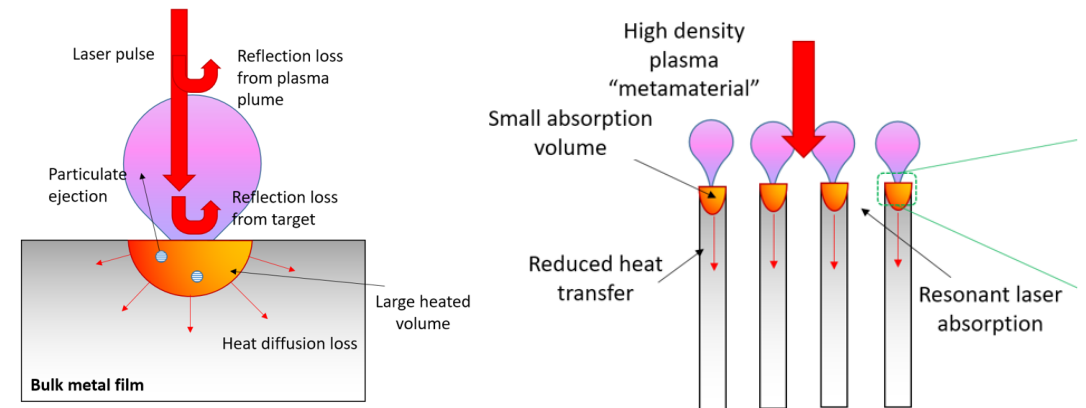
$$P = \frac{1}{2} T I_{sp} g_0$$

Innovative Approach

- Beamed energy can deliver lots of power & energy to distant targets (very high total specific power $>1\text{kW/kg}$)
- Key idea: laser ablation for propulsion
- Target parameters: momentum coupling coefficient ($C_m > 10 \text{ N/MW}$) and specific impulse ($I_{sp} \gg 1000\text{s}$)



Why plasmonic metamaterials?

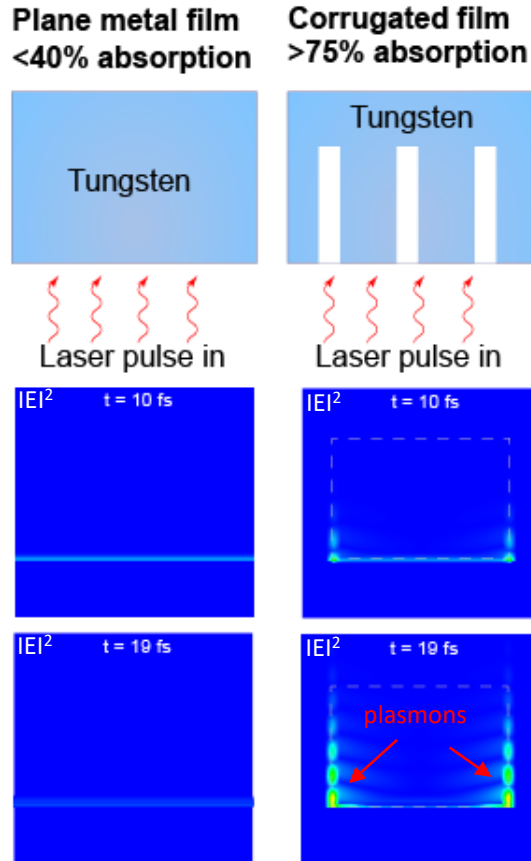


- Better control of ablation process: Heat flux, plasma plume, laser-plasma interaction. Objective: maximize laser absorption in plasma.

Prior and ongoing work

Theoretical modelling

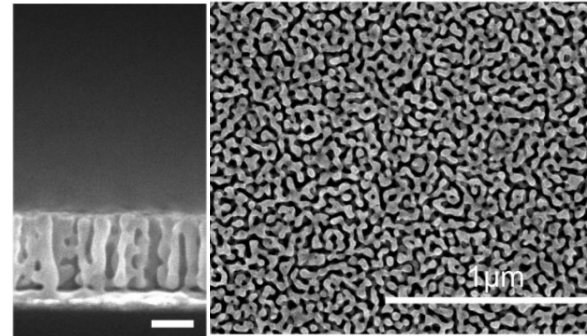
- Objective: understand and predict ablation processes in complex structures .



Deeper laser penetration and stronger field -> more efficient heat deposition

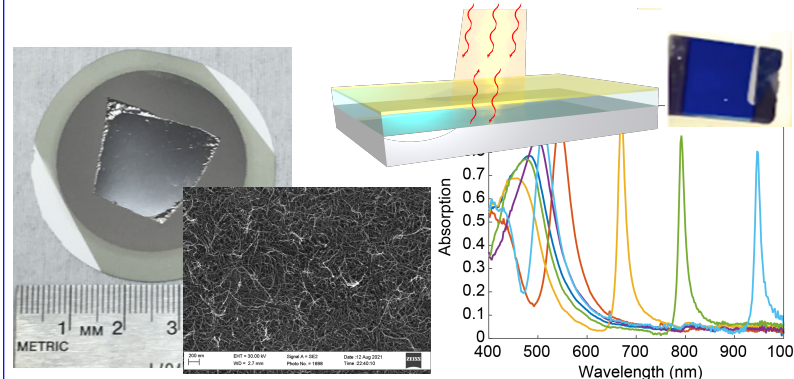
Target plamonic metamaterials: fabrication

- Objective: large area target materials with predefined features



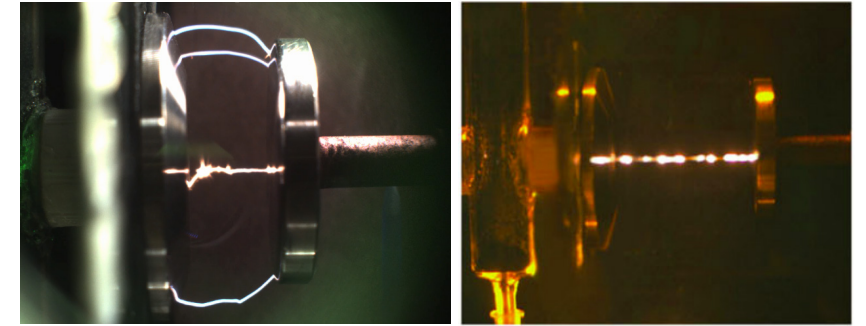
ACS Applied Energy Materials 2, 164 (2018)

- Large area nanostructures with controlled chemistries



- Fabrication of nanostructured target materials with desired micro and nanoscale features over larger areas

Laser induced plasmas



Nature Communications 11, 1 (2020)

- Demonstration of air breakdown control with laser heated micro & nanoparticles
- Can lower breakdown threshold and guide discharge along predefined paths

System architecture modelling (minor effort)



Nano Letters (submitted)

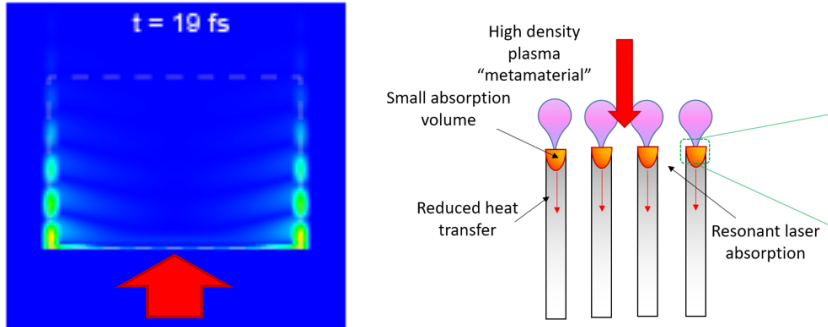
- We have simulations and models for estimating time, forces, and delta-V for demanding orbital maneuvers
- Objectives: better understand the needs for momentum coupling and I_{sp}

Future explorations

Theoretical modelling

Objective 1:

- Examine multiphysics interactions (light + heat transfer + molecular dynamics)



- Predict ablation rates and efficiency

Objective 2:

- Examine laser plasma interaction (absorption and ionization onset) →
- predict plasma spatio-temporal evolution and temperature →
- understand average velocity of plasma species and their interaction with the target

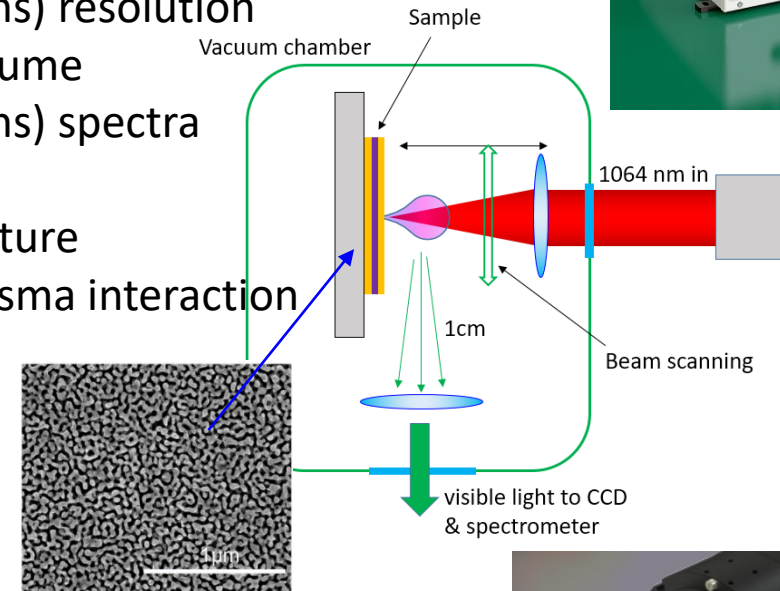
Team: Ho-Ting Tung, Pavel Shafirin



External collaborators: Aerospace corporation, NASA Marshall, Breakthrough Initiatives, Northrop Grumman

Experimental capability

- *In-vacuo* measurements of ablation
 - High area measurements (>10 mJ)
 - Ultrafast (ns) resolution of plasma plume
 - Ultrafast (ns) spectra acquisition:
 - temperature
 - laser plasma interaction
-



~5 ns laser (1064nm, 532nm), >100mJ



iCCD (3 ns gating; down to 180 nm)