Large-Area Nanotextured Surfaces for Passive Dust Mitigation: Project Updates and Key Questions

LSIC Lunch Meeting

August 17, 2023

Smart Material Solutions, Inc.:
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University of Texas, Austin:
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Team: Andrew Tunell

Agenda

- Introductions
- Passive dust mitigation concept
- Phase 1 findings and publication
- Phase 2 objectives
- Phase 2 achievements
- Key questions

Smart Material Solutions

NASA SBIR Phase II Project

TEXAS
The University of Texas at Austin

Passive Nano- and Micro-Textured Dust-Mitigation Surfaces in Space-Grade Materials Made with a Highly Scalable Fabrication Process (4/15/22 – 4/14/24)

Smart Material Solutions

Dr. Stephen Furst (PI)
Founder and CEO
PhD in Mechanical Engineering specialized in precision engineering

Dr. Nichole Cates
Senior Scientist
PhD in Materials Science specialized in electronic materials

Lauren Micklow
Mechanical Engineer
MS in Mechanical Engineering

Dr. Sidney Cox
Technical Consultant
PhD in Physical Chemistry

UT Austin

Dr. Chih-Hao Chang (co-PI)
Associate Professor Mechanical Engineering
Nanostructures and Nanomanufacturing Lab

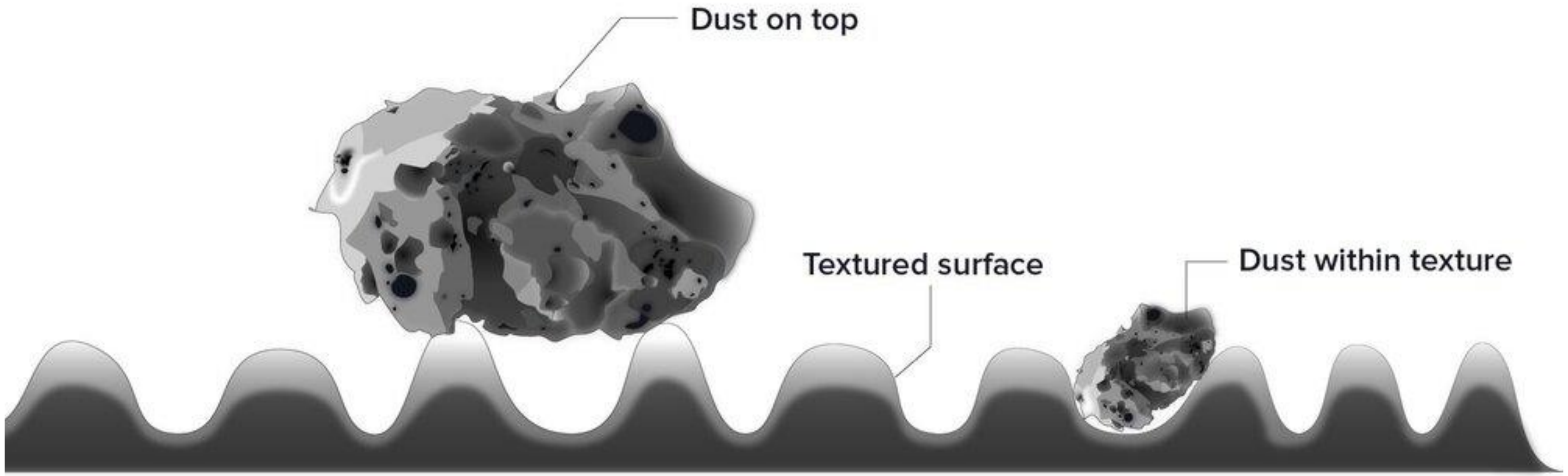
Students
Andrew Tunell

NASA

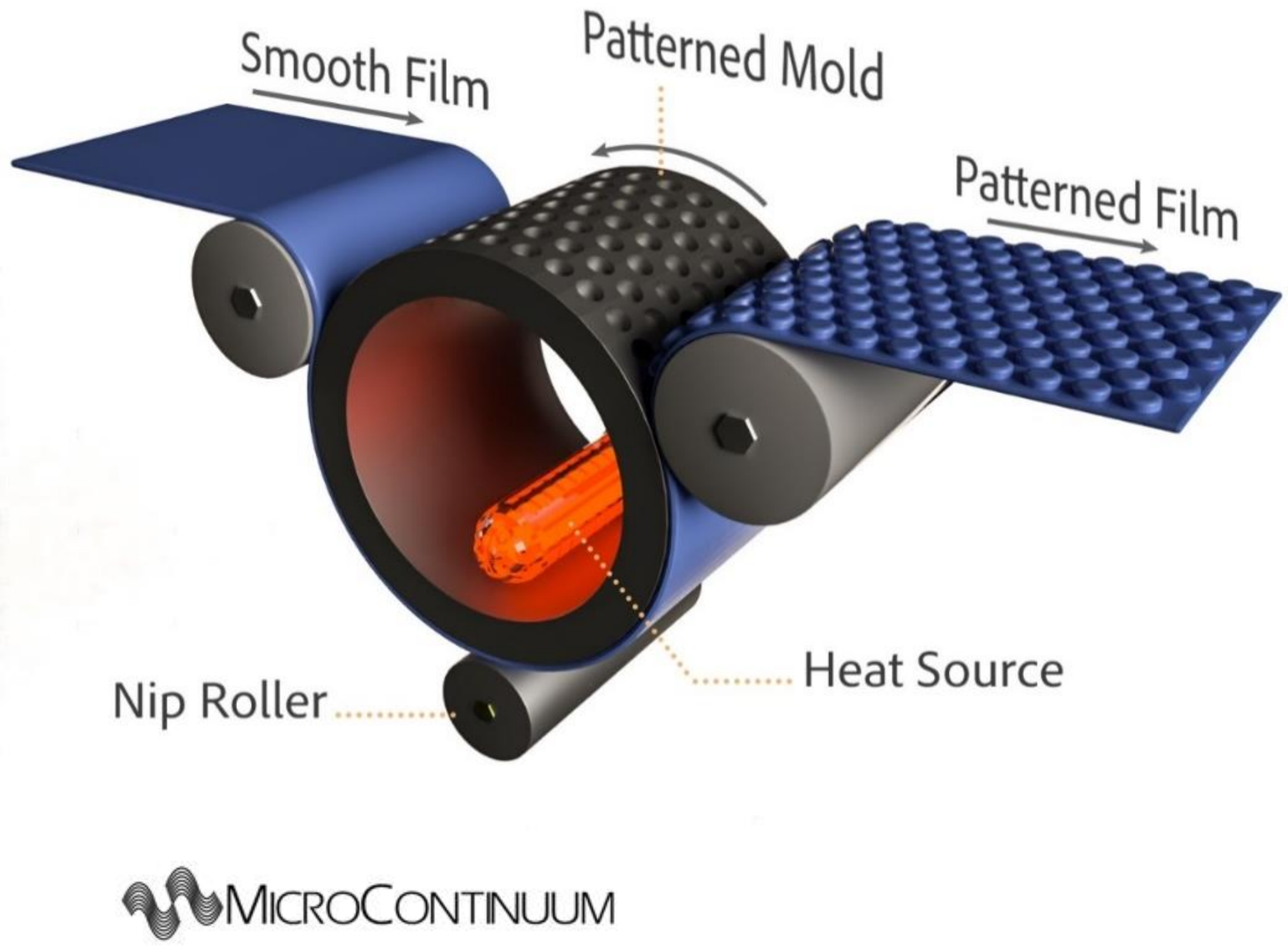
Glen King, Chris Wohl, Lopamudra Das
NASA Langley Research Center

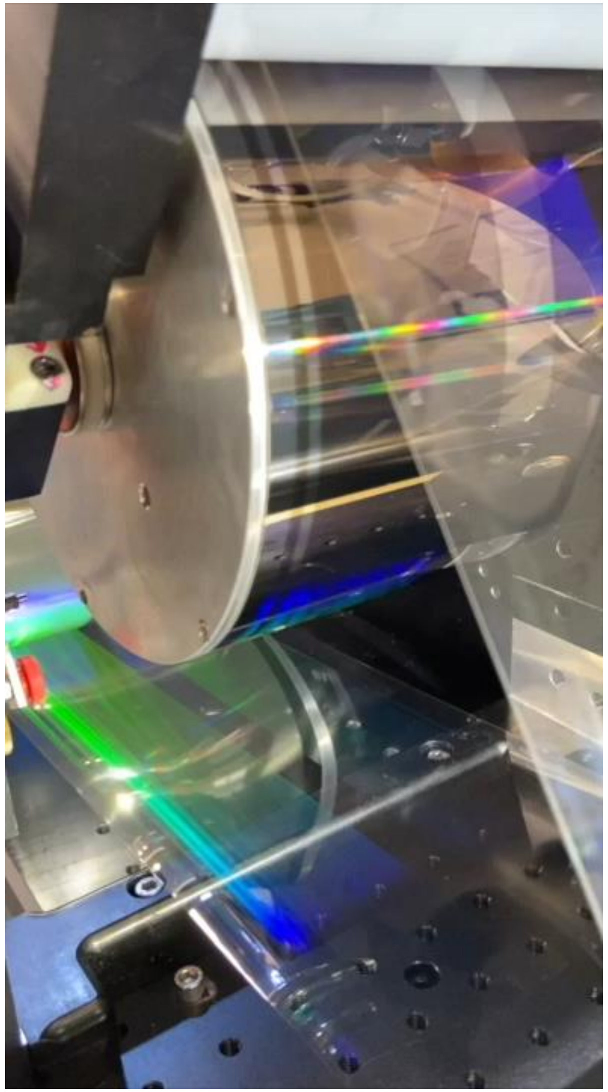
Concept for Dust Mitigation

- Minimize contact area between dust and surface
- Avoid trapping particles
- Lower surface energy
- Maximize surface hardness
- Minimize charging..?



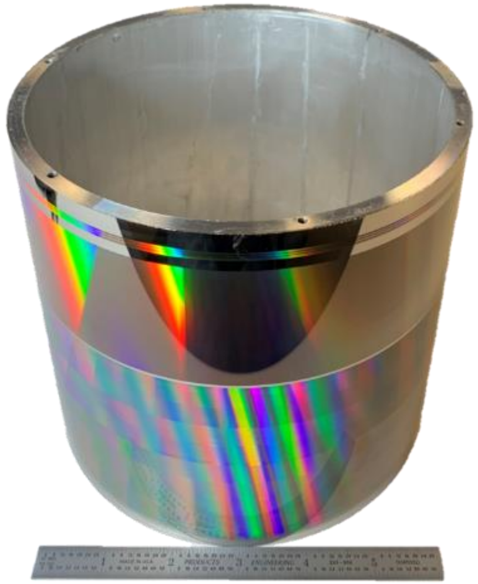
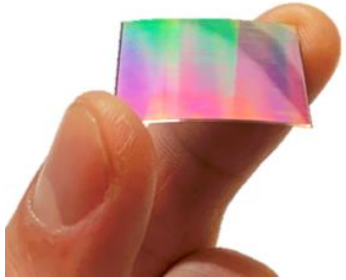
Roll-to-Roll Nanopatterning for Large-Area Coverage





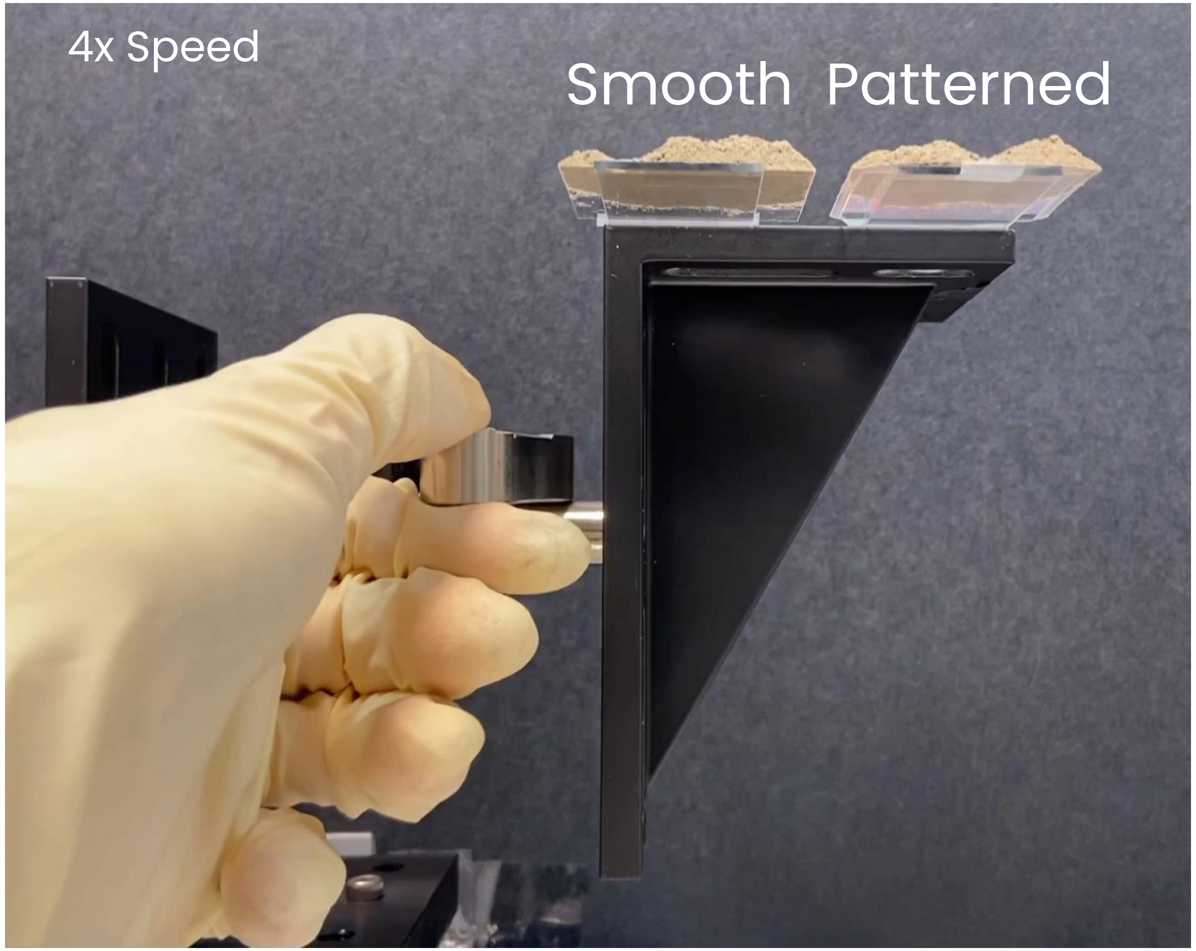
Our Core Technology

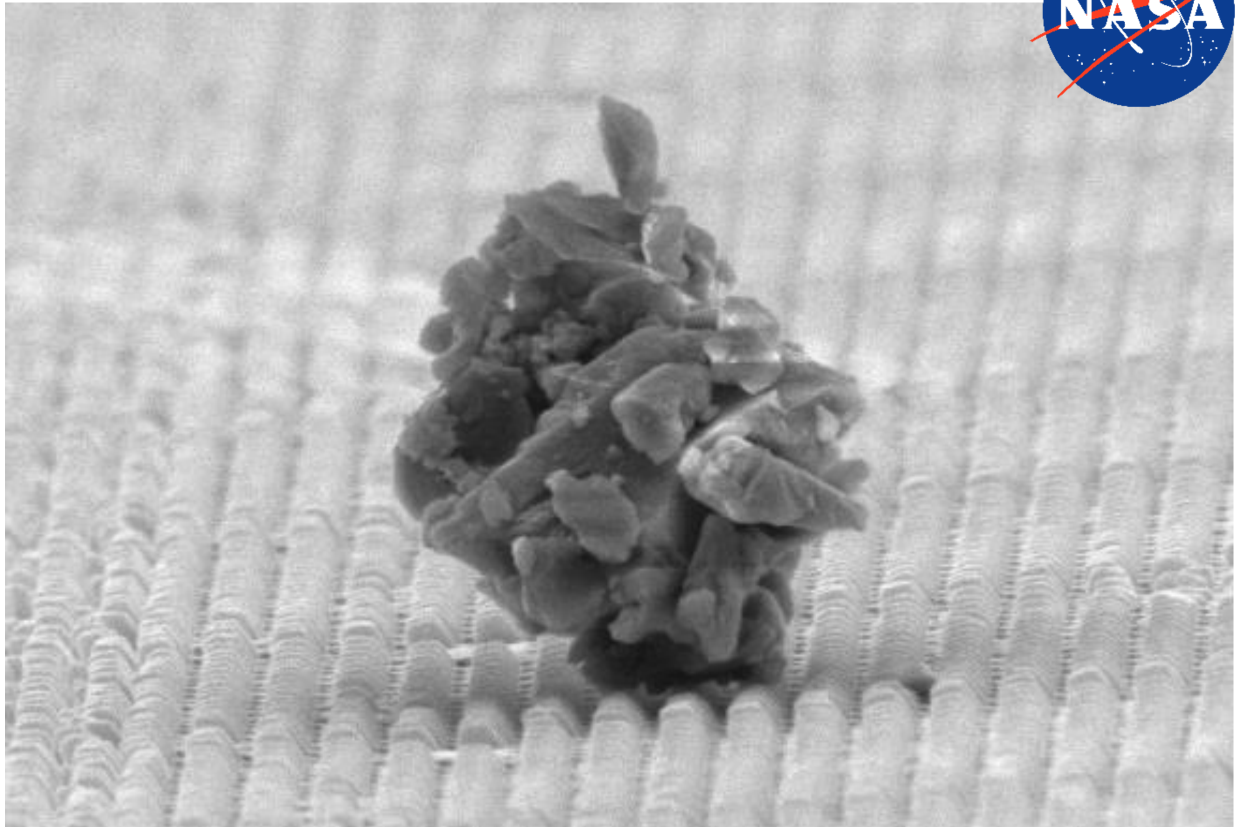
Micro and nanopatterned molds for nanoimprint lithography

Prototype Molds	Cylindrical Drum Molds	Cylindrical Sleeves	Shims
			

Phase I Results

Nanopatterned surfaces to reduce dust adhesion



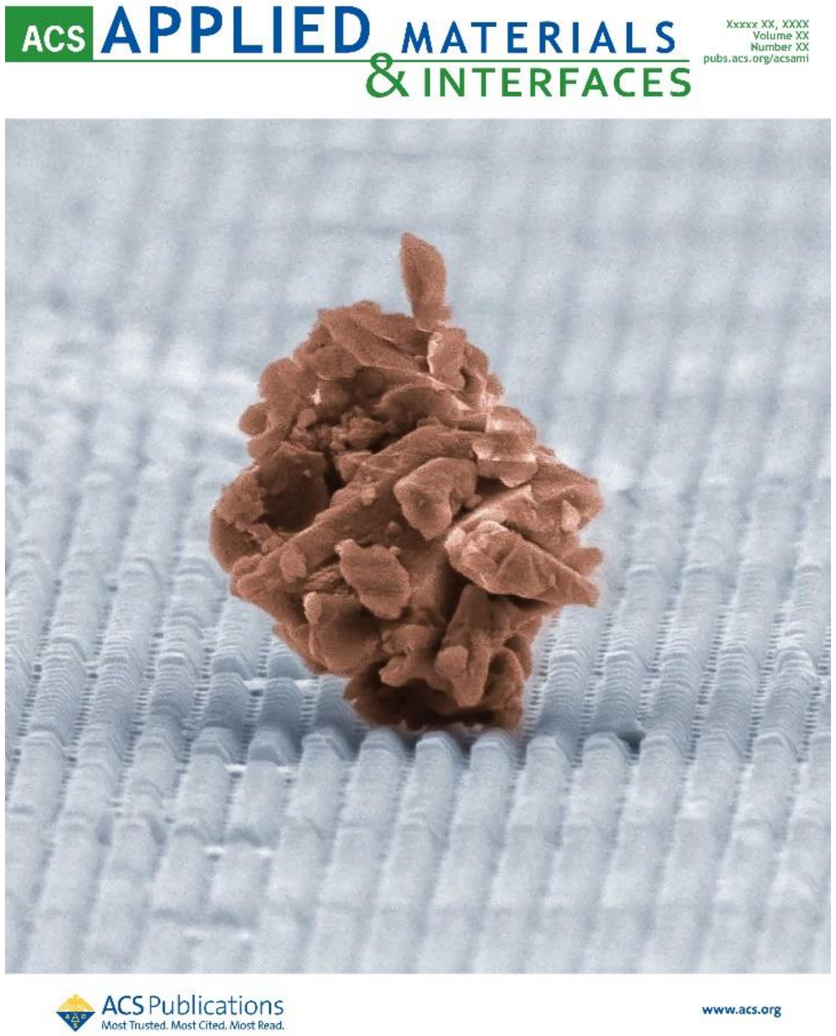


ACS Appl. Mater. and Interfaces. Samuel Lee et. al. 10.1021/acsami.2c19211

Publication and IP Status

Publication:

Engineering Large-Area Antidust Surfaces by Harnessing Interparticle Forces



Provisional Patent:

- *Dust Mitigating Nanotexture and Process for Creating (May 17, 2022).*
- Jointly owned by SMS and UT.
- SMS retains option to exclusive license.
- PCT conversion due May 17, 2023.

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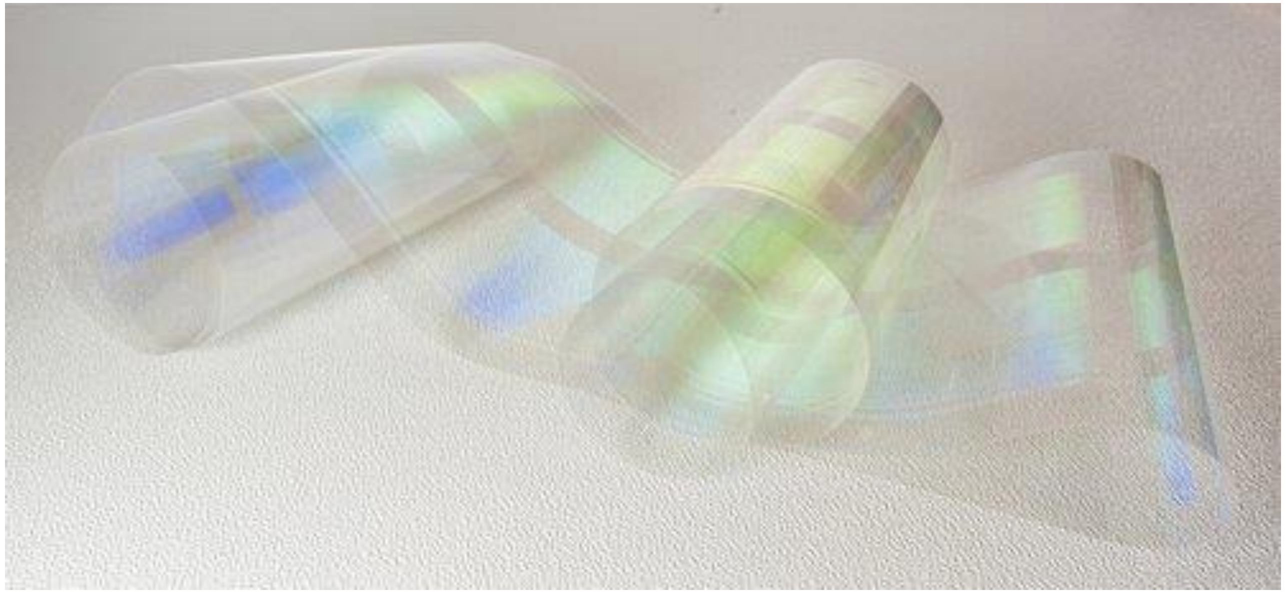
Phase II Objectives

TEXAS The University of Texas at Austin

1. Improve our understanding of the **physics that drive particle adhesion** and optimize structure design based on that understanding.
2. Create optimal dust mitigating surfaces at **large scale** and in **application-relevant materials and form factors.**
3. Prove that these benefits will work in the relevant **lunar environment** in addition to an Earth-based lab.

Desired Outcomes

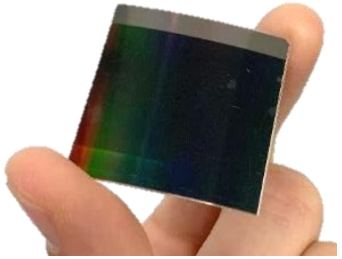
1. Adapt a dust-mitigating structure to a surface need by a customer with a scalable process
2. Find a market that motivates scale of full roll-to-roll process

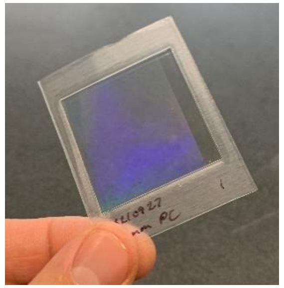


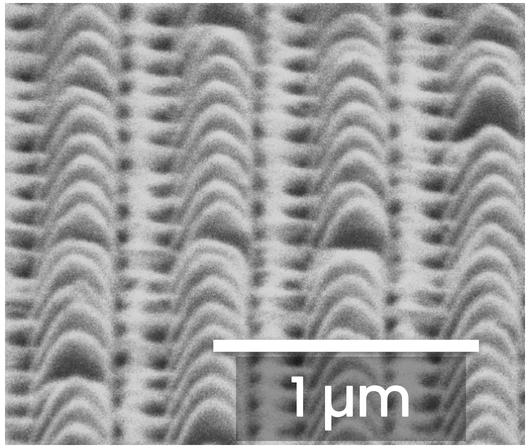
Year 1 Achievement:
New pattern – 400 nm

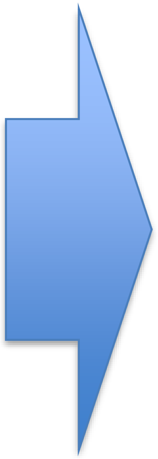
Phase 1:

500 nm pitch
35x35 mm shim



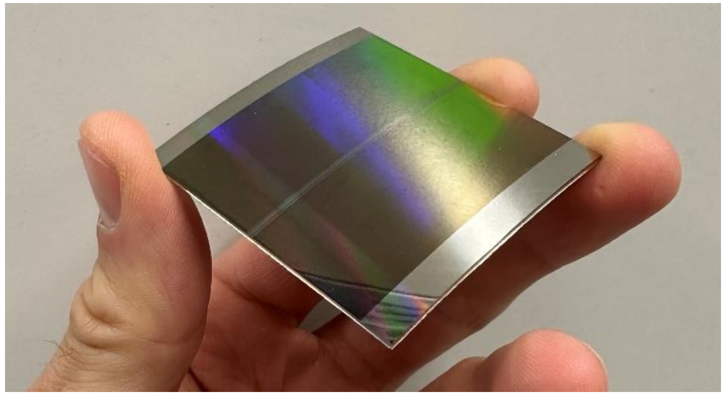


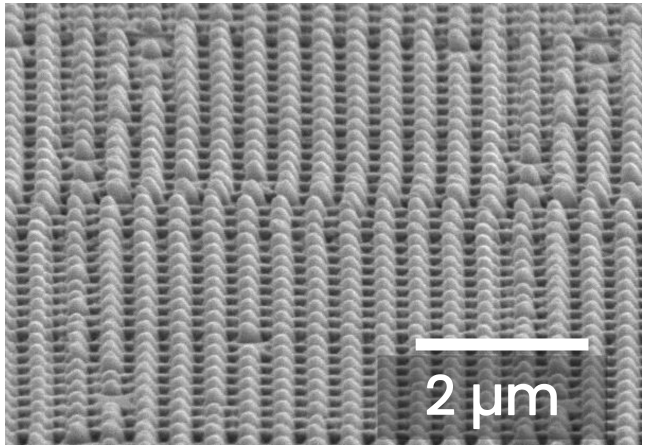


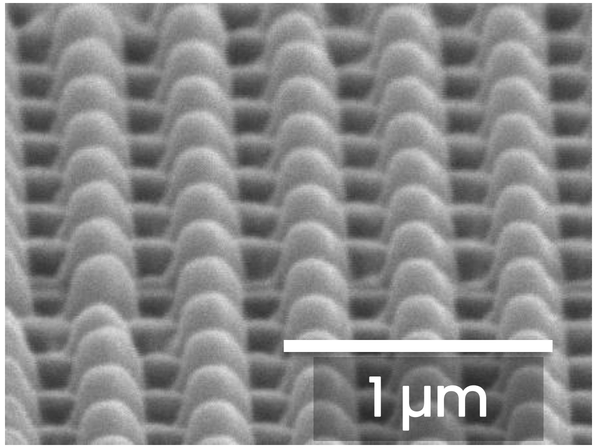


Phase 2:

400 nm pitch, 75x75 mm shim

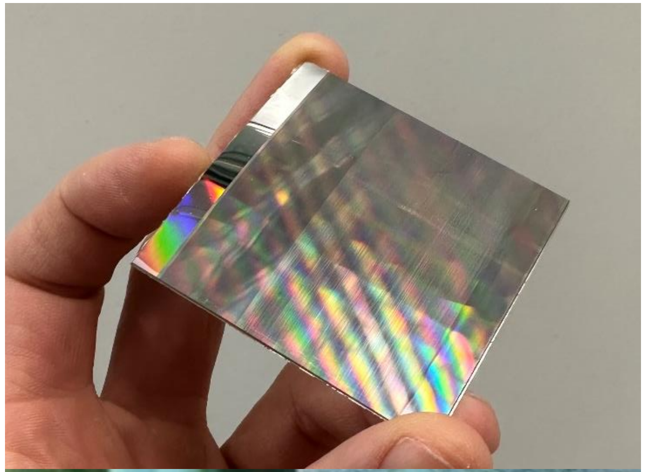


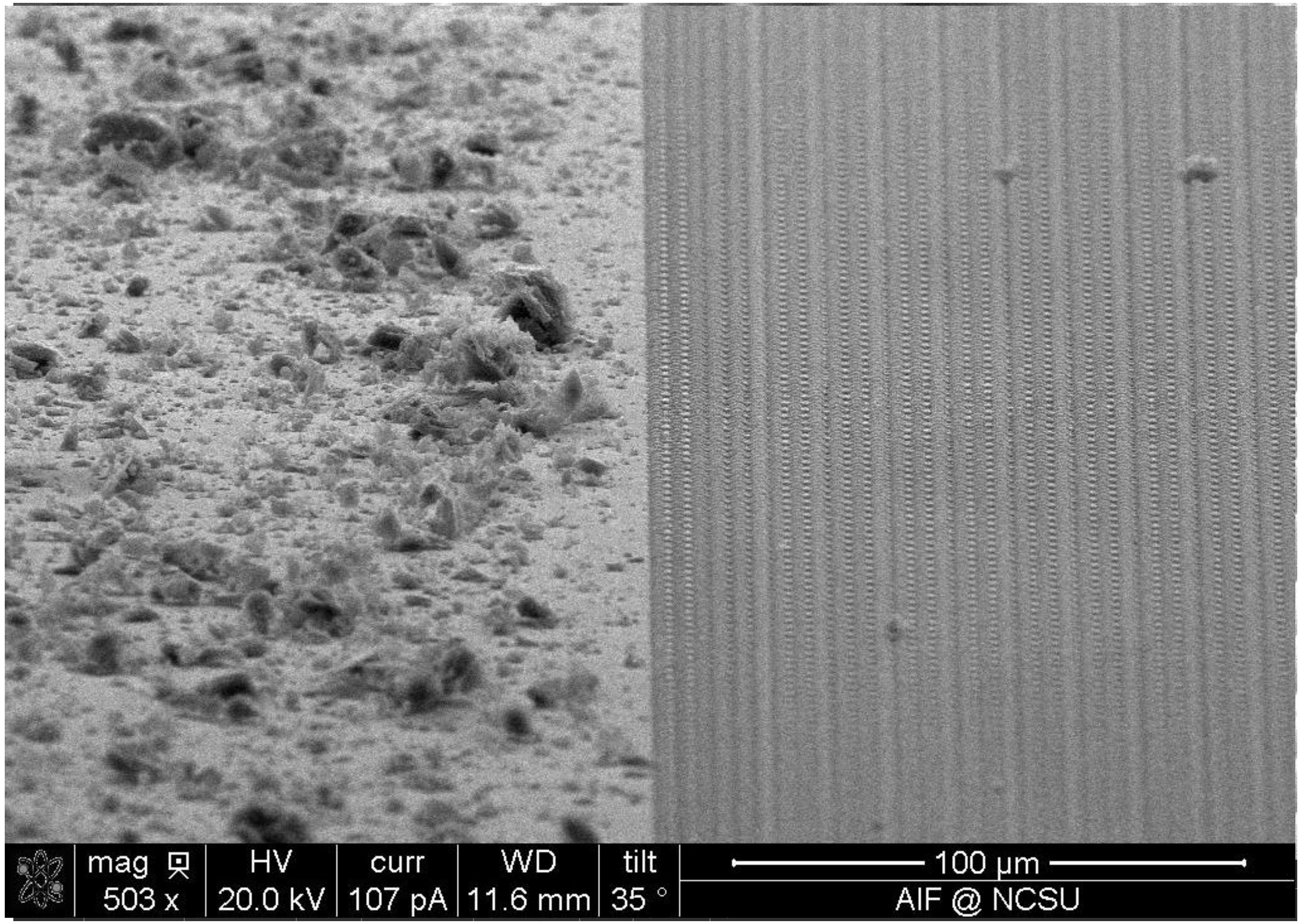




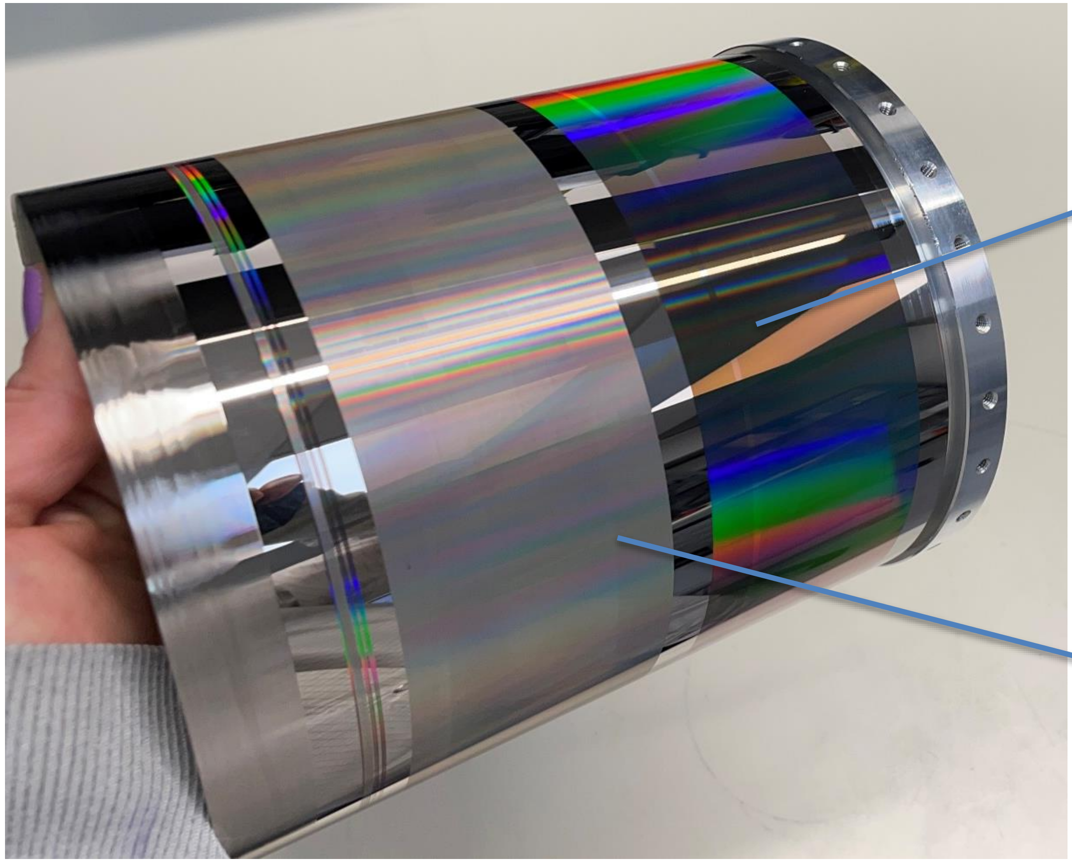
Year 1 Achievement:
New pattern – hierarchical

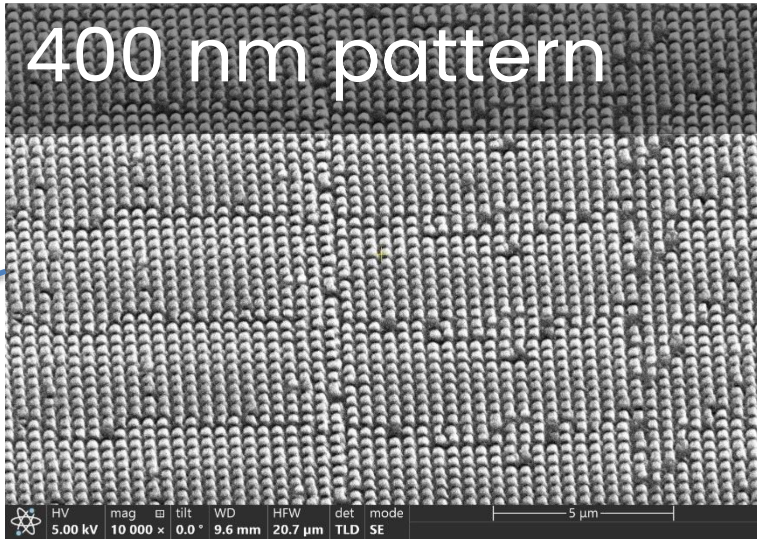
500 nm features on top of 4 μm features (*Army-funded work*)

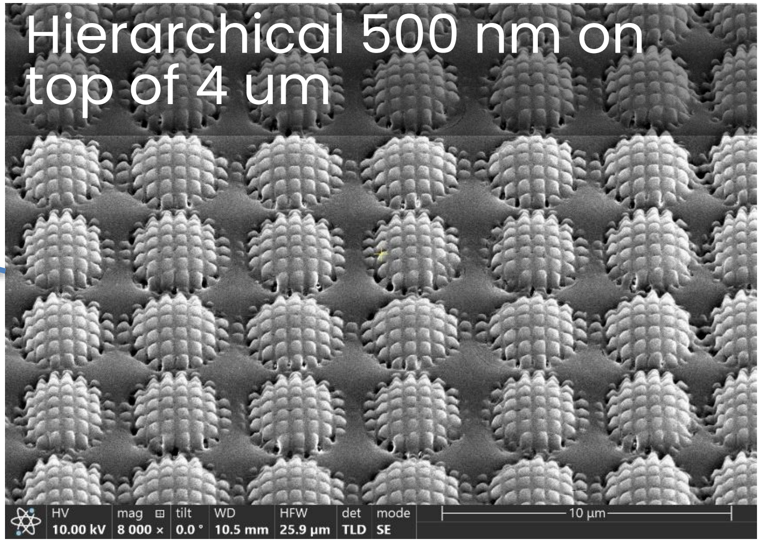




Year 1 Achievement:
Seamless 6" sleeve





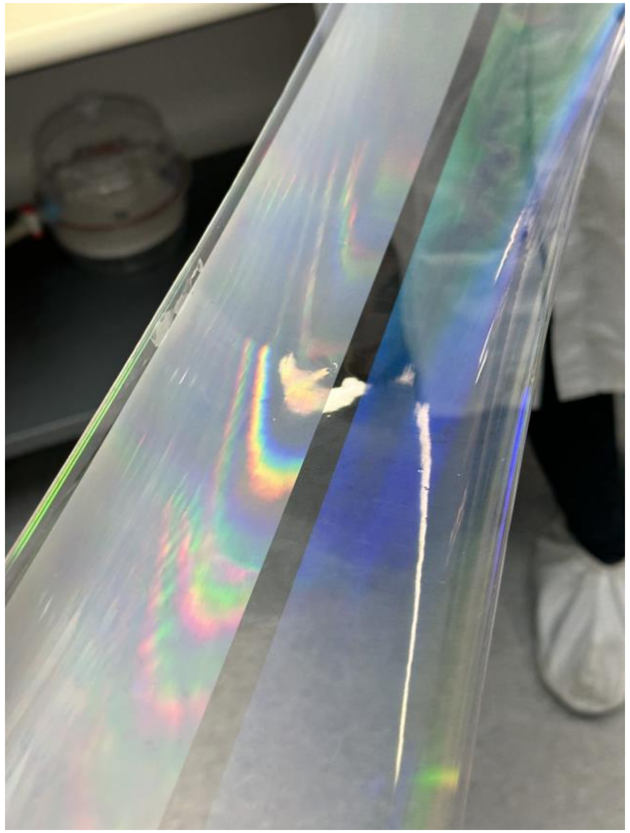


Year 1 Achievement: *Roll-to-roll imprinting*

More than 150 ft. of imprinted polycarbonate

MicroContinuum



Year 1 Achievement: *Pattern transfer*

Material	Patterning Successful	R2R Compatible Process	Metrology Available	Dust Mitigating (destatic/silane)
Polycarbonate	✓	✓	✓	✓
CoC (Zeonor)	✓	✓	✓	✓
PET (Mylar)	X	X	✓	?
FEP	✓	?	X	?
PTFE (Teflon)	✓	?	X	?
ETFE (Tefzel)	✓	?	X	?
Polyimide (Kapton)	✓	?	✓	✓
Glass	✓	X*	✓	✓

? – not yet tested

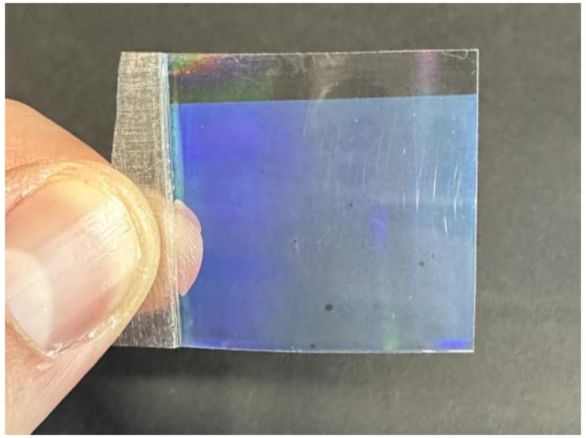
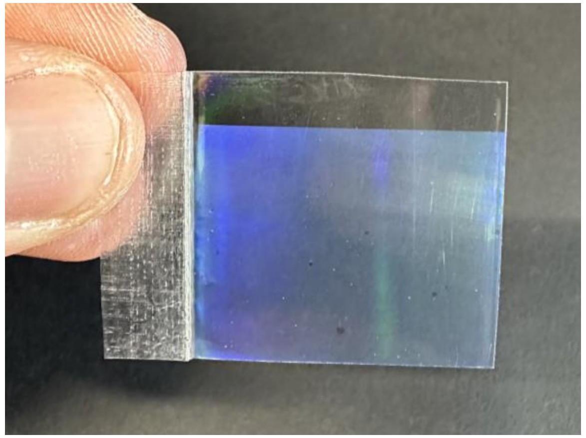
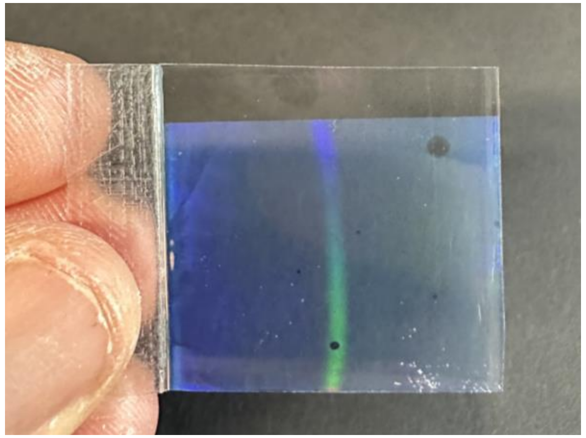
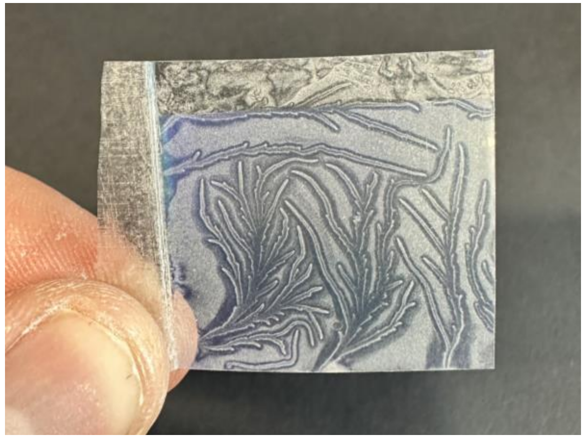
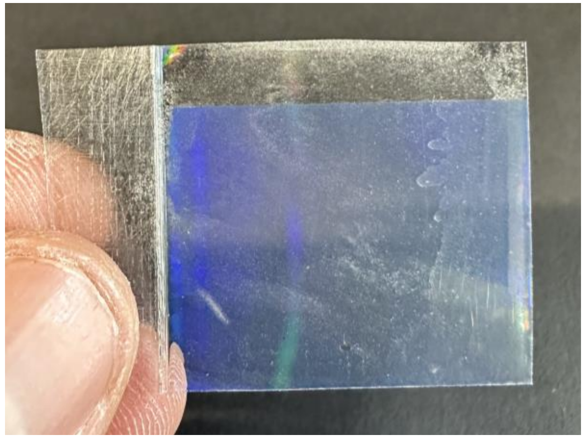
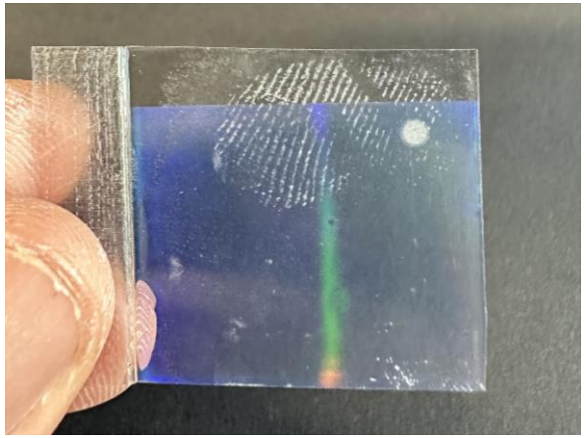
* – some R2R RIE has been done on the lab scale

Surprising Results

What really affects dust adhesion?

- ✓ Surface energy
- ✓ Surface texture
- ✓ Material hardness
- Static charge on the surface
- Contaminants on the surface
- Loading method

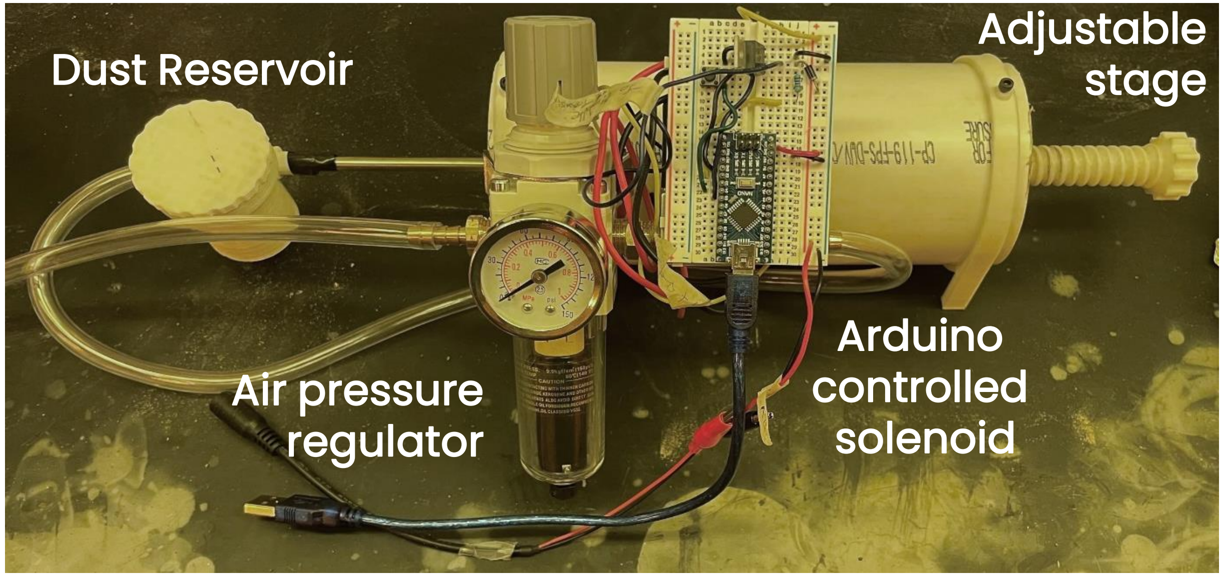
Static and Contamination

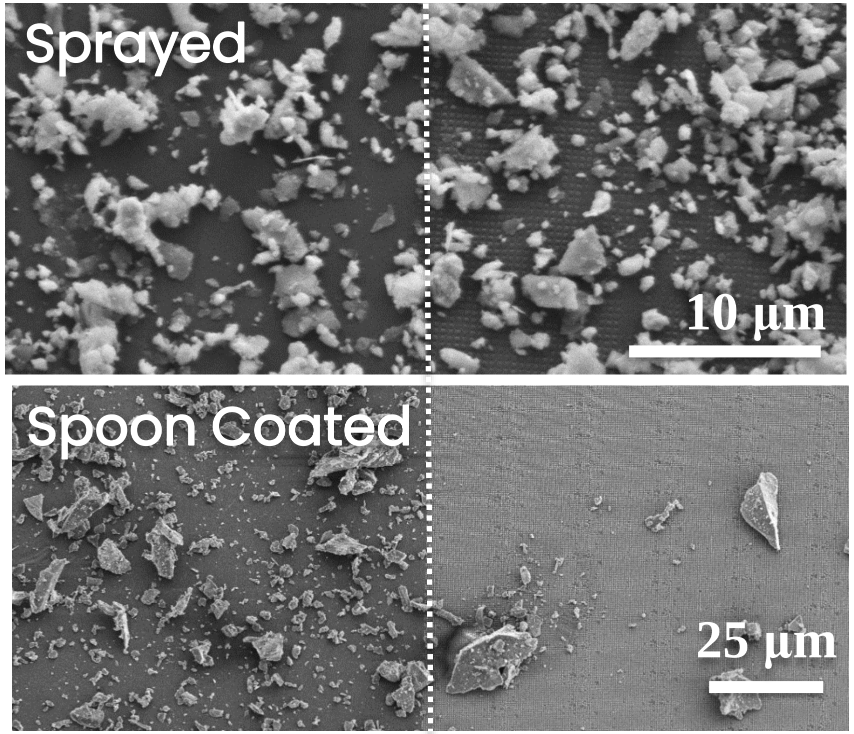
	As pressed	Pressed and rinsed with IPA	Pressed, rinsed, and contaminated
Before Dusting			
After Dusting			

Loading Methods

- Dramatic change (typically reduction) in dust mitigation performance when dust is sprayed at the surface as opposed to spoon coated
- New physics: velocity induced effects

Dust spray system:





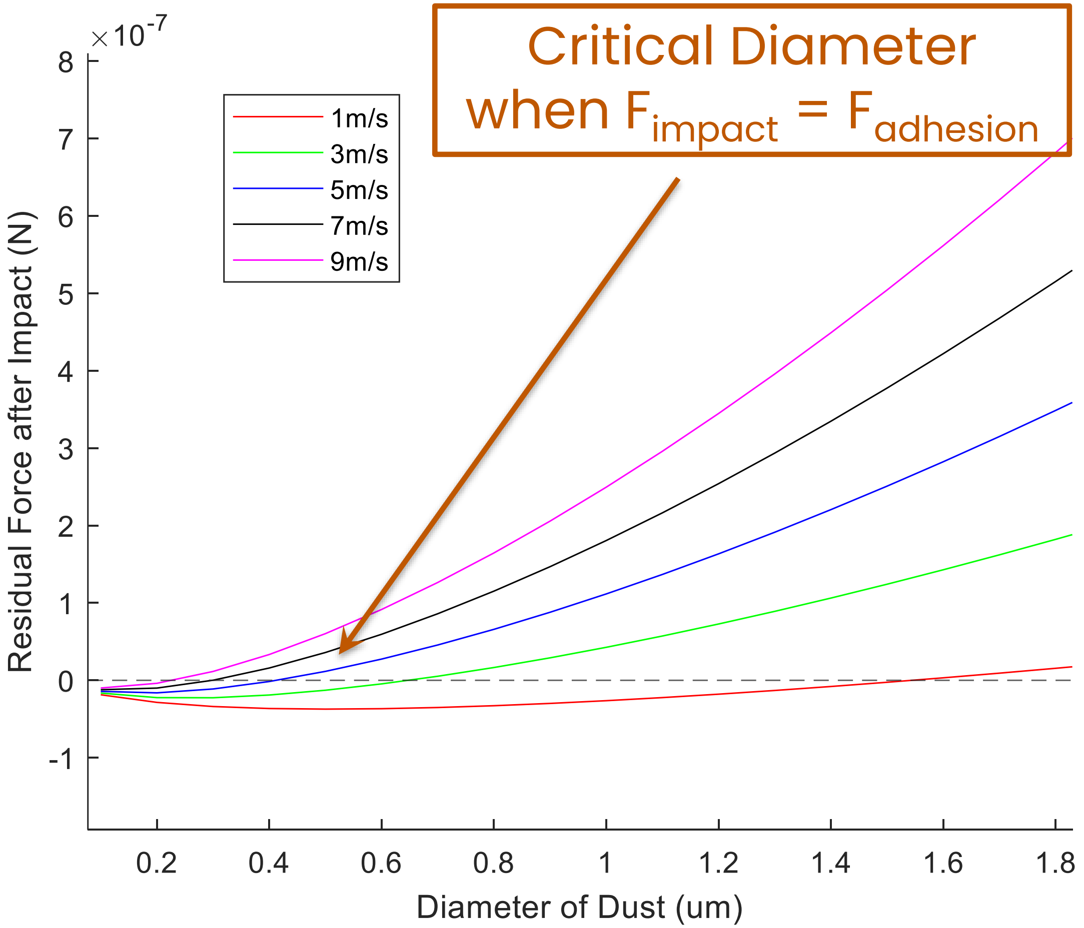
Understanding New Physics: Dynamic effects

- Prior tests based on **static conditions:** dust particle has no velocity
- **Dynamic effects**: Velocity increases momentum of large particles and prevents adhesion
- At high velocity, **only smaller particle sticks to surface** (acts as a filter), which is more difficult to remove
- If $F_{impact} > F_{adhesion}$, particle more likely to bounce vs stick to surface

$$F_{adhesion} = \frac{3\pi}{2} f_1 \frac{(R_{surface} * R_{dust})}{(R_{surface} + R_{dust})} (\gamma_{dust} + \gamma_{surface})$$

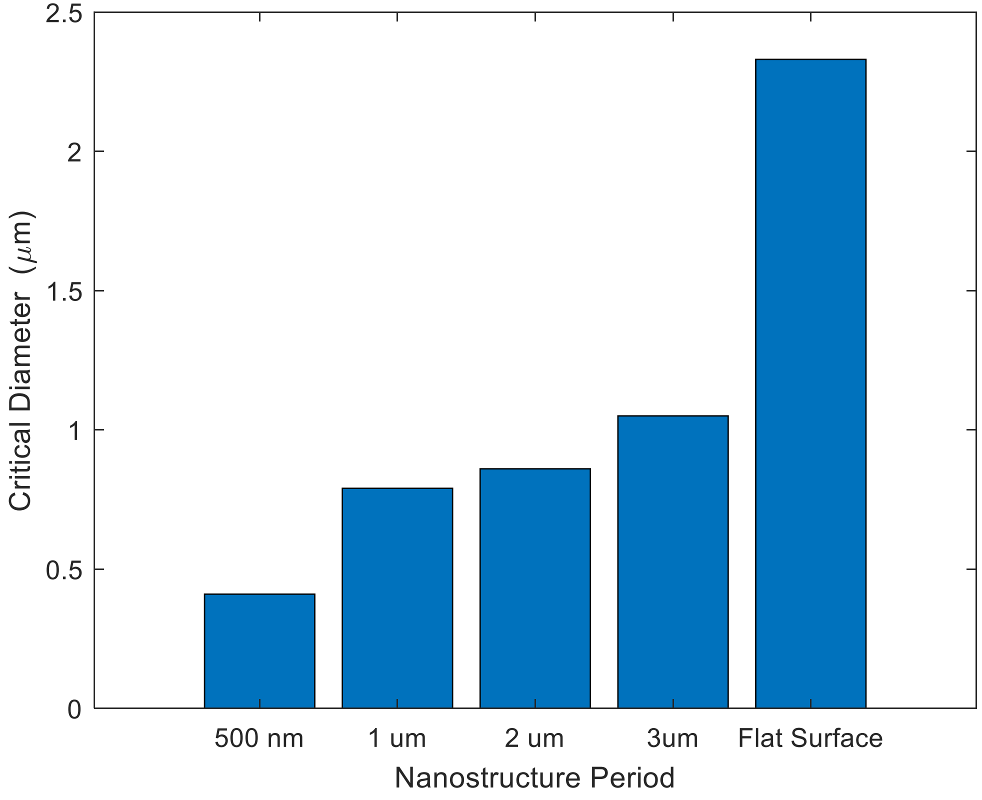
$$F_{impact} = v\sqrt{n * m * k}$$

(Impact Forces – Adhesion Forces)
On a 500 nm Periodic Structure

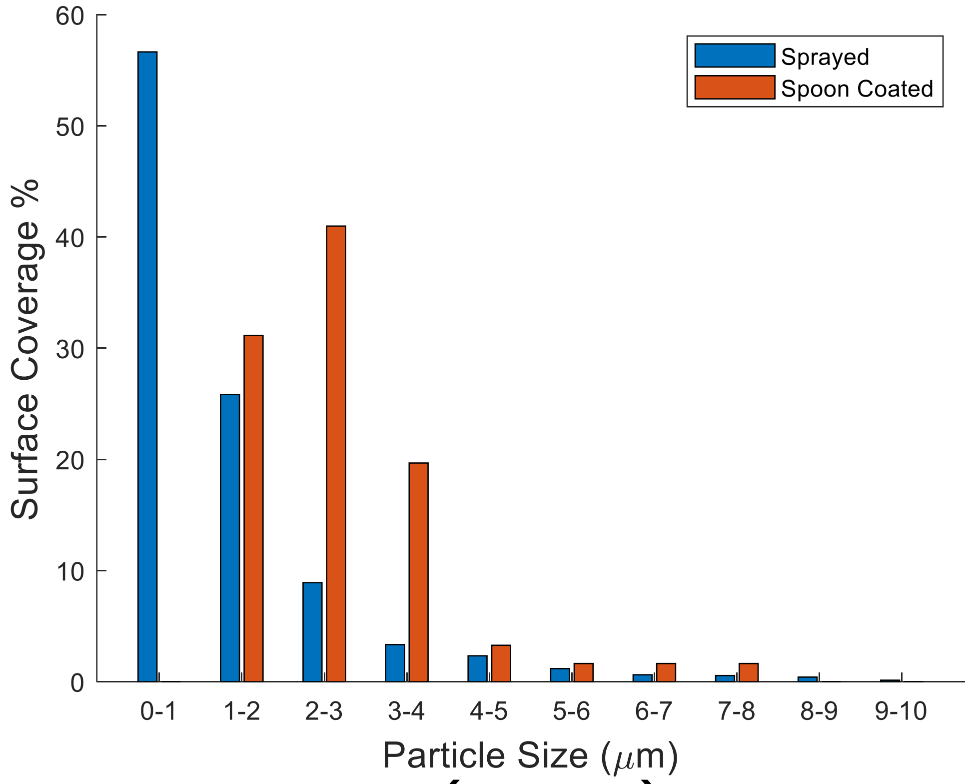


Key Challenge: *Velocity effect*

Critical Diameter of Particles Impacting at 5 m/s



Size Distribution of Residual Particles

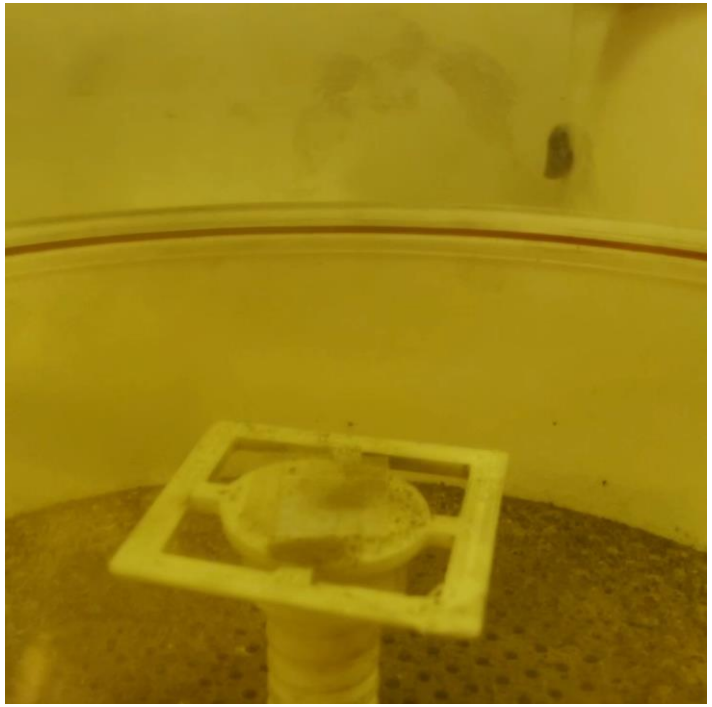


- Experiments for spray (dynamic) vs spoon-coated (static) indicate more smaller particles stick to surface based on histogram

Effect of Velocity and Particle Density on Aggregation

- Aggregation plays a major role in mitigation effect
  - High particle velocity can prevent aggregation
  - Sparce contamination with low particle density

5 Sprays @ 2 PSI



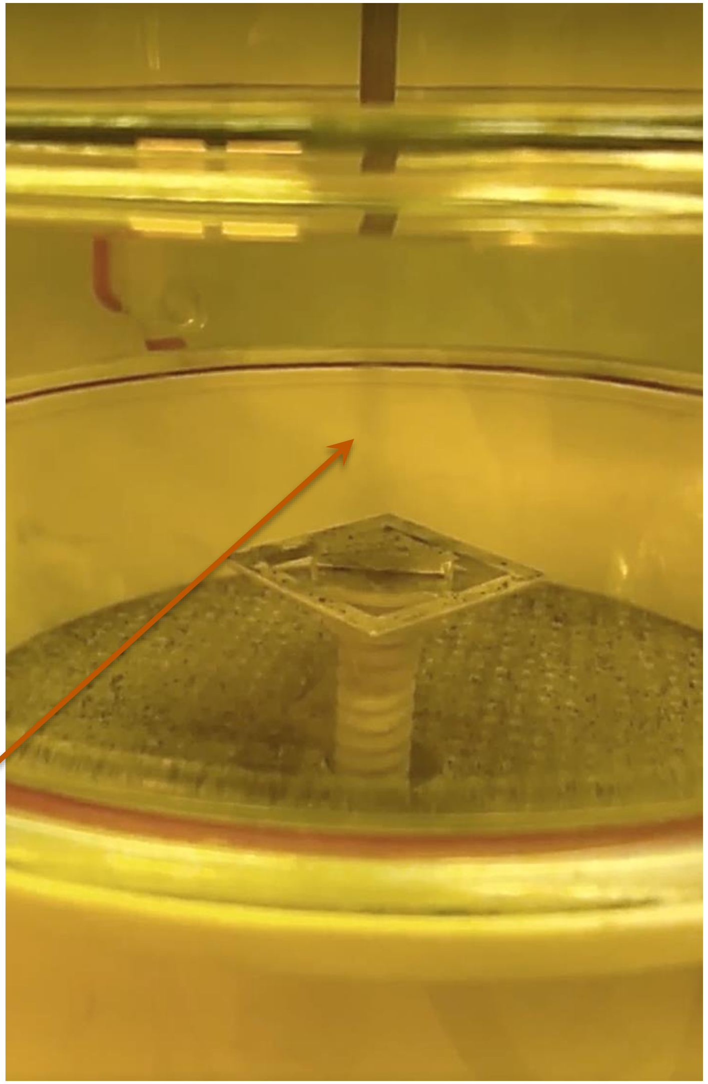
Video 1 Sprays @ .5 PSI

1 Sprays @ .5 PSI

Next Steps: Building an Understanding of Sparse Coating

- Additional Equipment to Test Velocity Dependance
  - Low Pressure Regulator
  - High Speed Camera

- Utilize new tools to identify small particles
  - Confocal Microscope misses very small particles between structure



Spray Pattern; unable to capture velocity on current equipment

Key Challenge: *Silane coating polymers*

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The University of Texas at Austin

Step 1:

Oxygen plasma etch or corona treatment

Step 2:

Vacuum desiccate with OTS

Next Steps:

More consistent and scalable coating processes

- Liquid phase deposition
- Alternate silane chemicals
- Anti-static coatings

*** Extremely inconsistent in coating polycarbonate

Most Promising Applications

Application	Large area (leverages R2R)	Polymer film based (easily scaled R2R)	Low touch / damage	Defect tolerant	Cleanliness is mission critical
Solar panels	✓	✓*	✓	✓	✓
Radiator films	✓	✓	✓	✓	✓
Camera lens cover	X	X	✓	X	✓
Seals and joints	X	X	X	✓	✓
Rover wheels	✓	X	X	✓	X
Rover panels	✓	X	✓	✓	X

* – lamination of polymer-based coating may raise questions around durability

*We're most compatible with **film-based, large area, low touch** applications*

Key Questions

Technical Development:

- How can we controllably add static/charge to a sample?
- Can we reduce static charge with a thin coating/SAM?
- Long term, in-situ durability of films and adhesives

Business:

- Which customers and applications are willing to pay for these capabilities at scale?
- Program of record or investment to support extended research / Phase IIE?

Extra Slides

Smart Material Solutions, Inc.

Raleigh, NC

Growing Team!

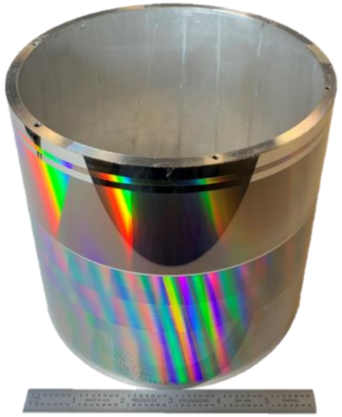
- Four full-time and two part-time employees
- PhDs in mechanical engineering, materials science, and chemistry

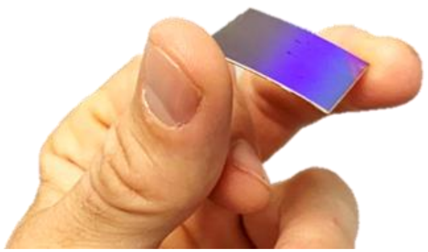
Facilities & Equipment

- 2,000 ft^2 facility in Raleigh, NC with lab and offices
- Equipment agreements with NCSU, Duke, and UNC

Core Technology

Seamless nanopatterned drum molds and shims for nanoimprint lithography



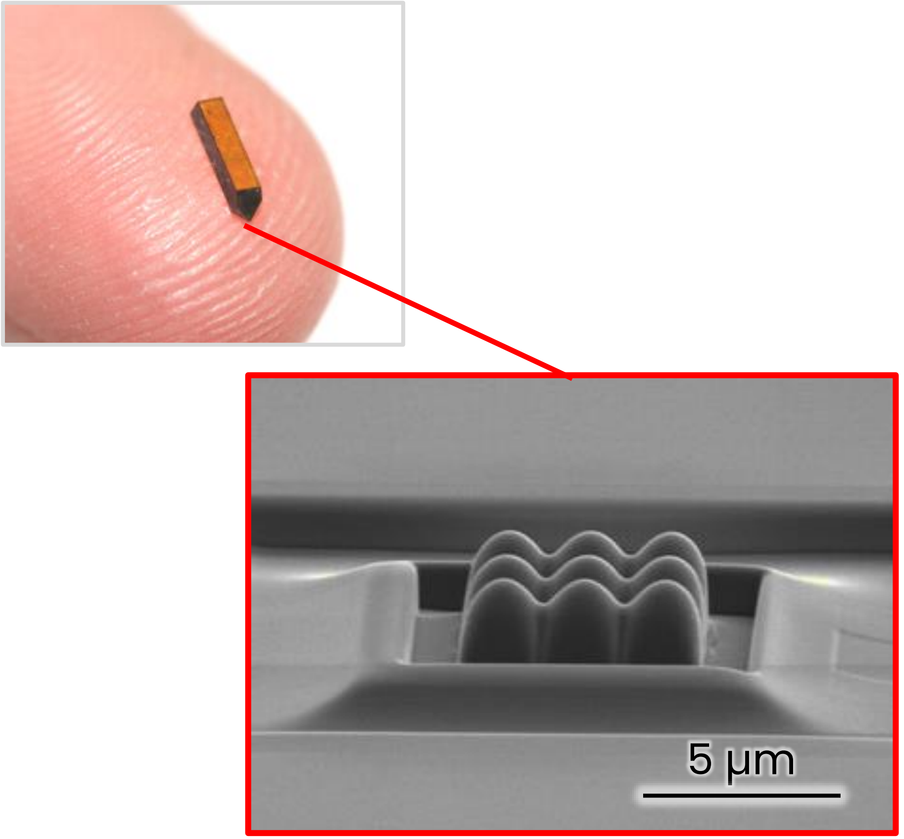


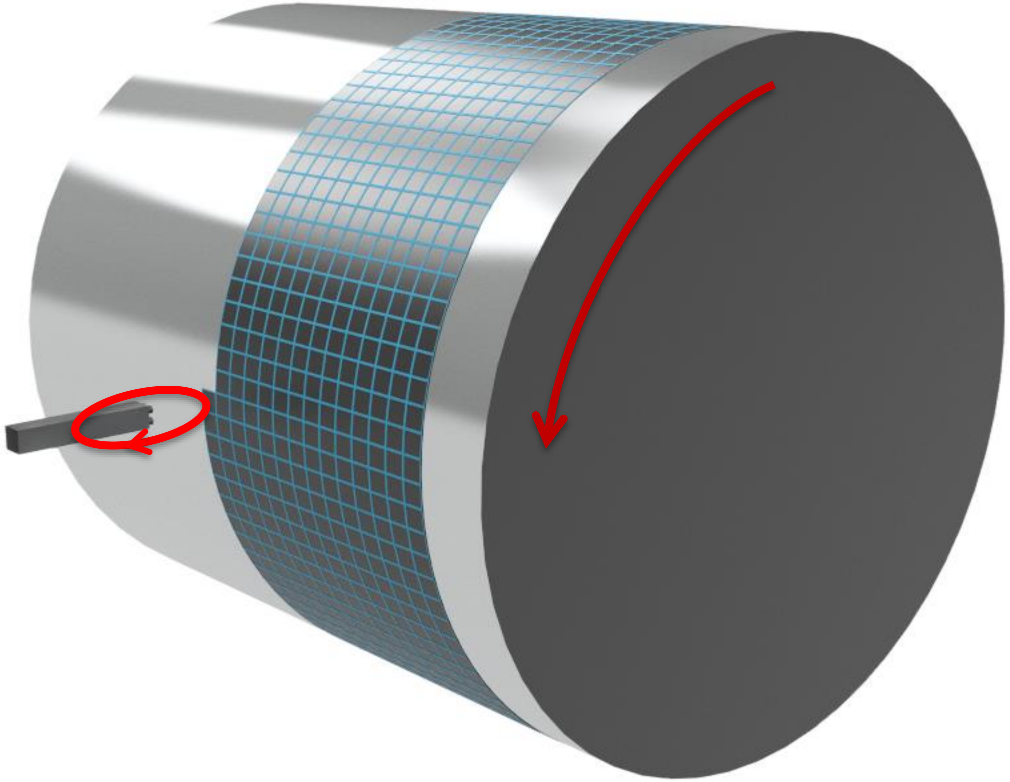
Funding

and industry partners

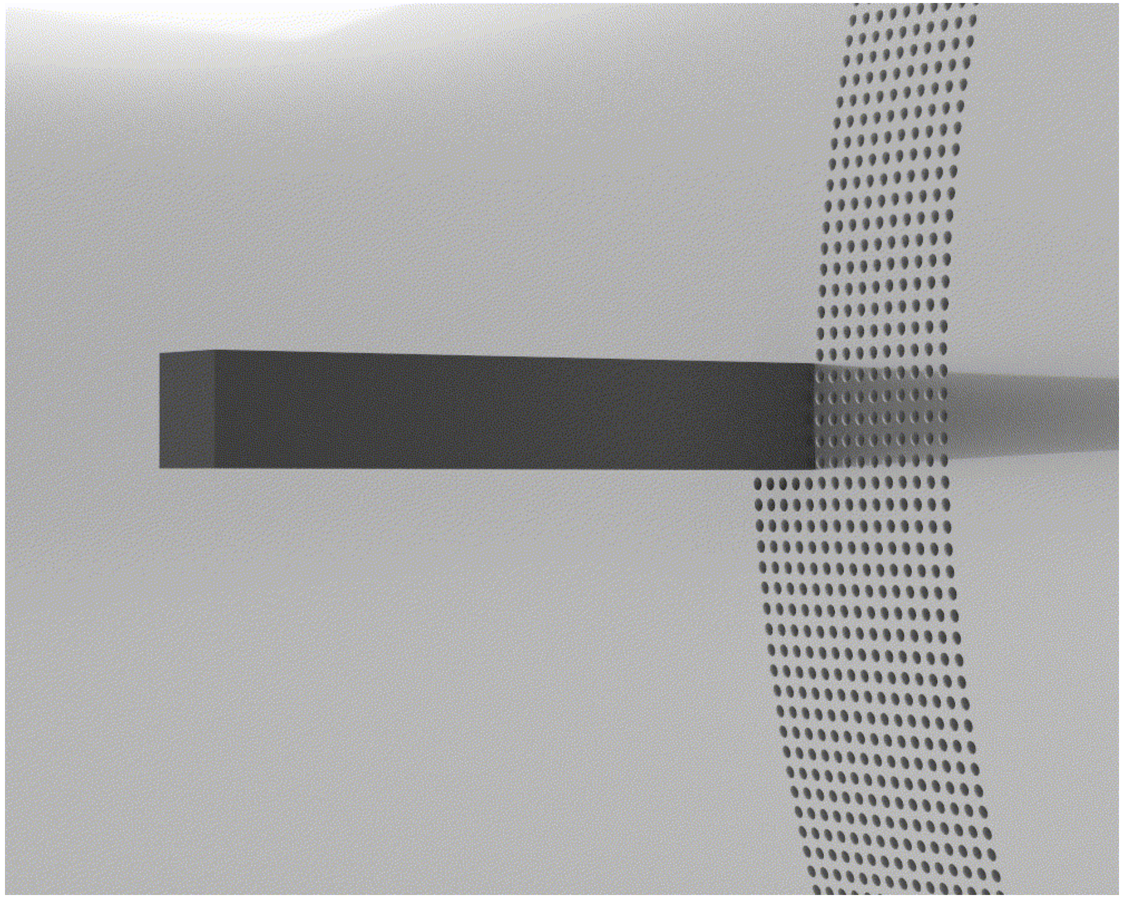
Our Core Technology

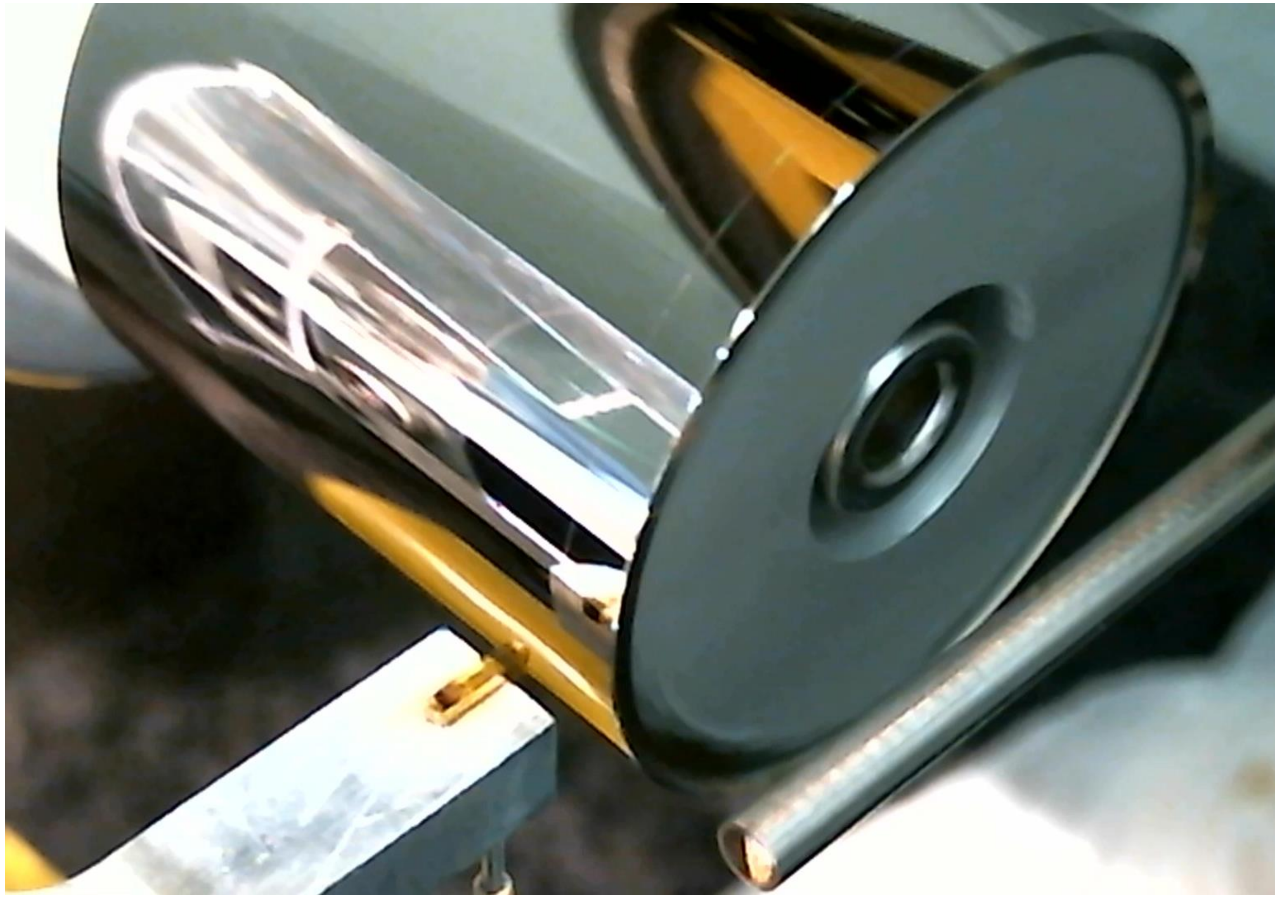
Ultrasonic Nanocoining





Nanocoining Process





~ 500x faster than ebeam lithography