Proximity Glare Suppression for Astronomical Coronagraphs
(NASA SBIR Phase 1)

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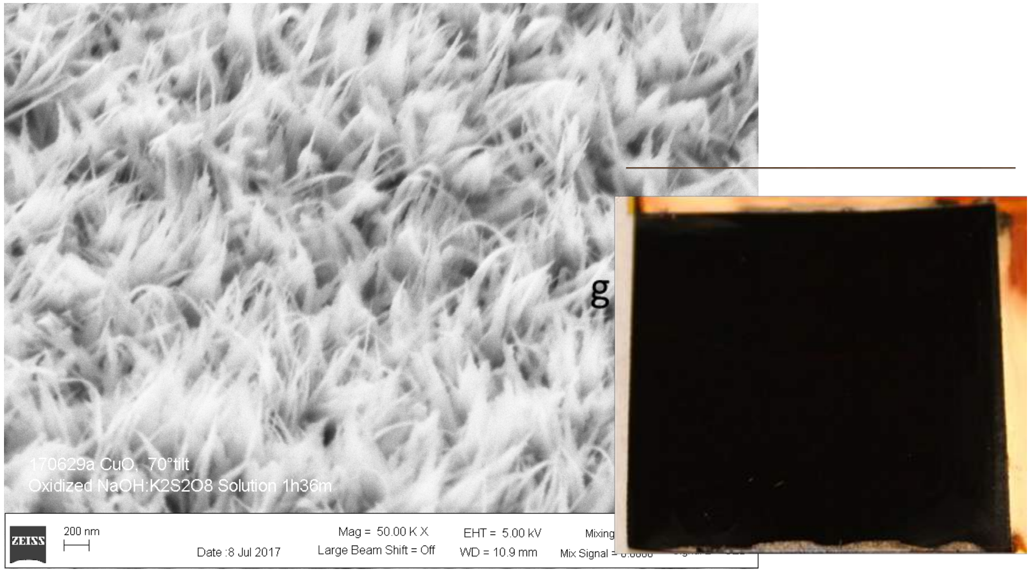
Outline

- Intro to Nanohmics
- High-level vision for proximity glare suppression development
- Anti-reflective surface structures for glare suppression
- FDTD modeling results
- Copper Oxide development and characterization
- Flexible Black Silicon
- Conclusion



About Nanohmics Inc.

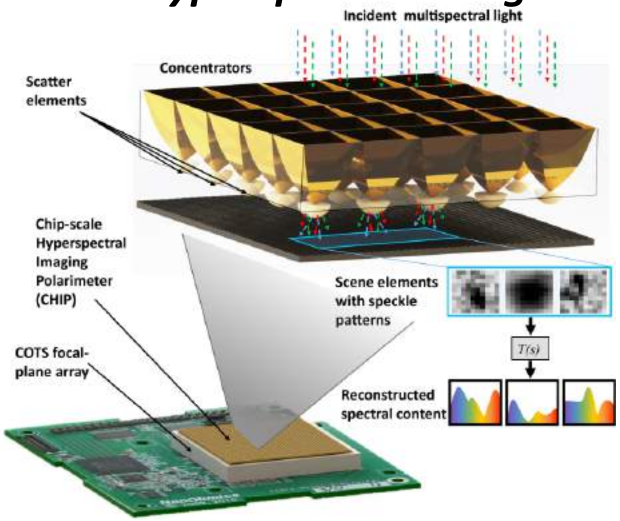
30 Scientists + Engineers located in Austin, TX

Electro-optics
- Surface scattering, BP(R,T)DF
- System level optical design
- Optical signal+image processing
- Infrared emissive devices

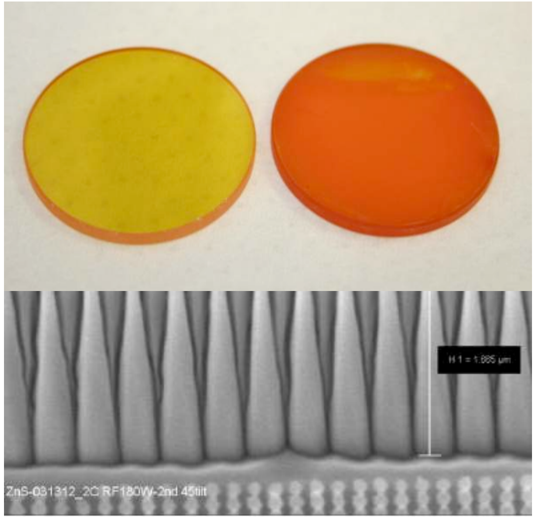
Material Science
- High-temperature dielectrics
- Thin-film coating deposition
- Advanced dielectrics
- Semiconductor nanostructures

Instrumentation
- Biological Transduction
- Low-noise electronics
- Digital signal/image processing
- Rapid full-custom prototyping

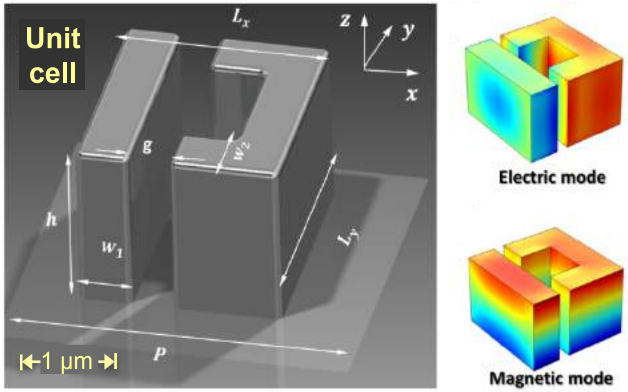
CHIP Hyperspectral Imager



Anti-reflective coatings



Metamaterial optics

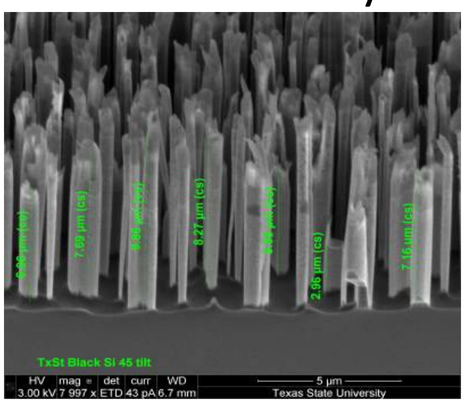


High-level Vision

- Coronagraphs require suppressing starlight to a 10^{-10} contrast level
- Black coatings must be compatible with Flat + Curved surfaces
- Coating materials must be robust against pealing, flaking, outgassing, and cleaning.
- Planar surfaces (i.e. Metal Oxides) have *non-negligible* specular reflection!

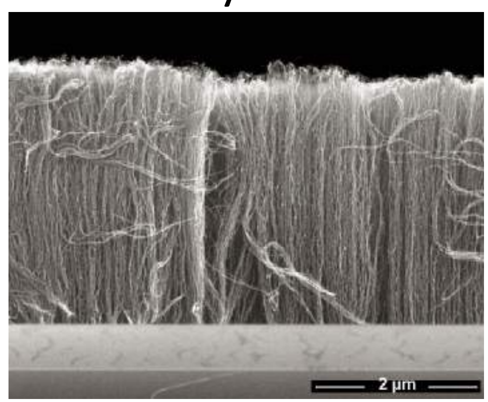
Black Silicon

- <0.5% reflection in Visible + IR spectrum
- Development at JPL
- Fragile to touch
- Flat surfaces only?



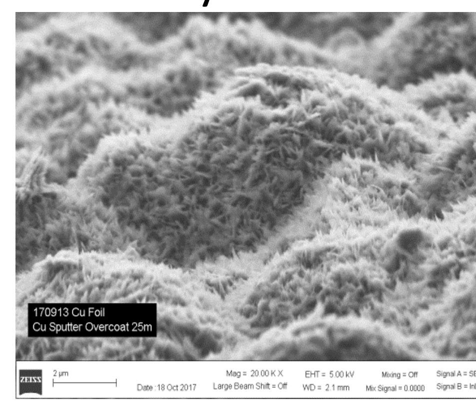
Carbon nanotubes

- 99.5% absorption in visible spectrum
- Development at NASA
- Coat 3D surfaces
- Durability?



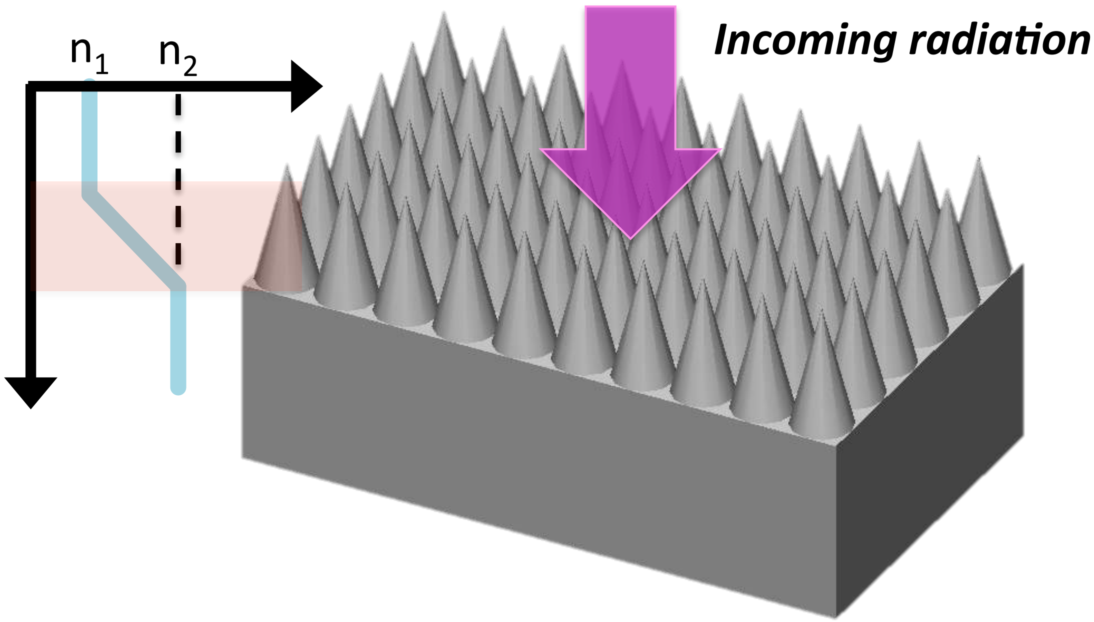
Metal oxides

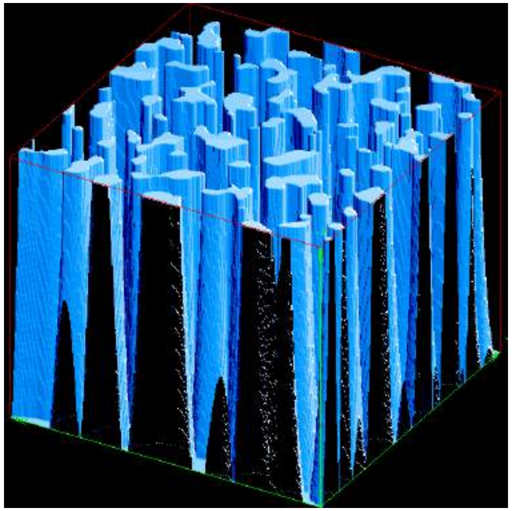
- Cu, Zn, stainless steel
- Visible + IR spectrum
- Foils, tapes, substrates
- Large area coverage
- Durability?



Develop graded-index anti-reflective structures to suppress reflection from super black absorbing materials over broad angle of incidence/spectrum!

Anti-reflective surface structures (ARSS)



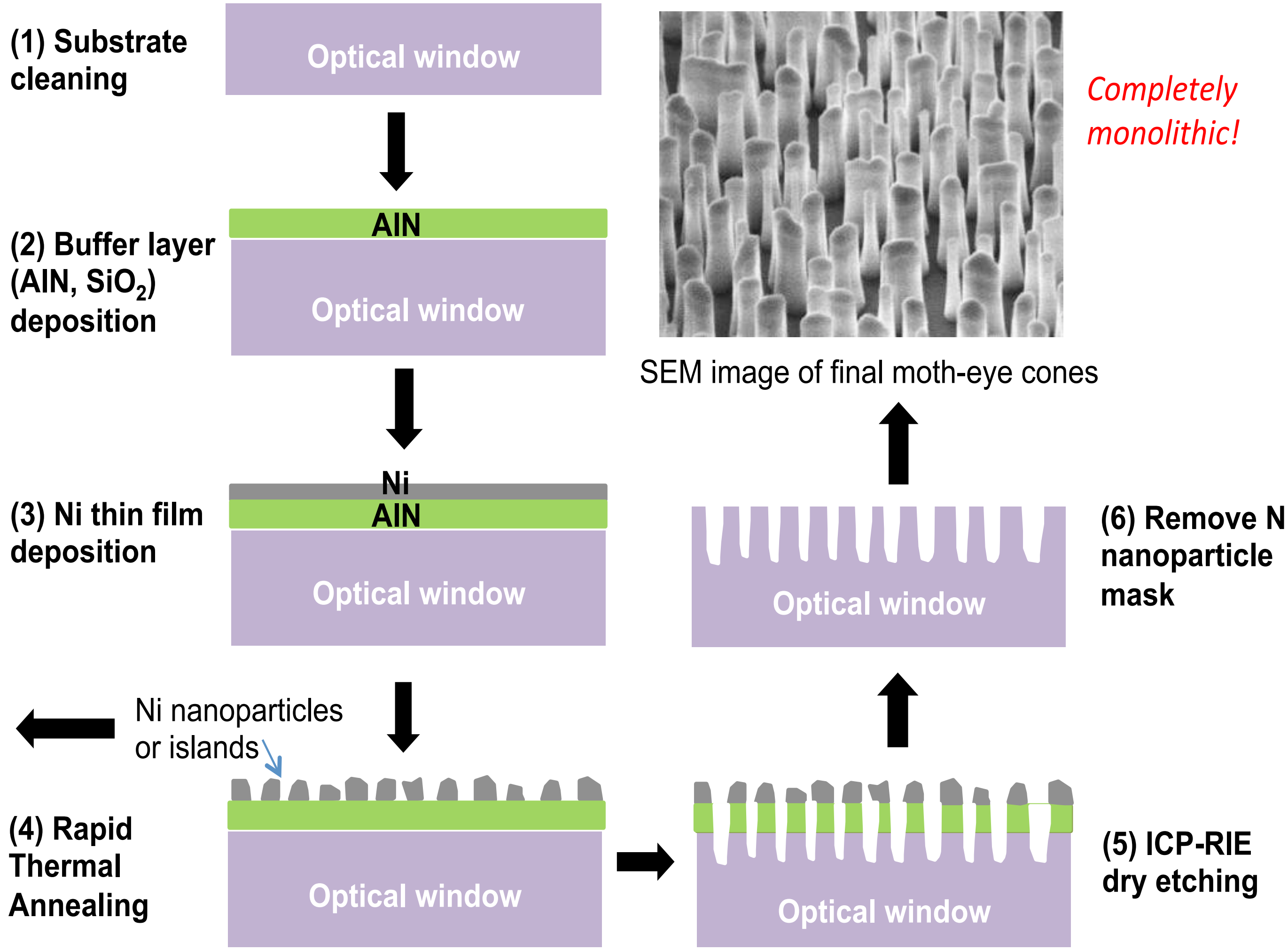


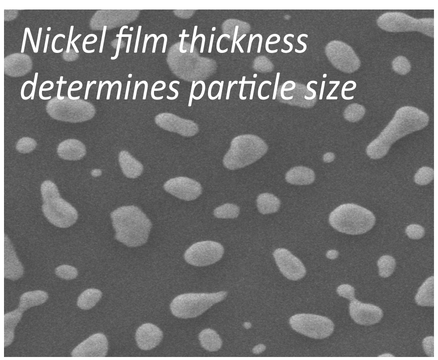
Impedance matching: Graded-index effective medium comprised of sub-wavelength surface structures!

<u>Advantages of anti-reflective surface structure (moth-eye's)</u>

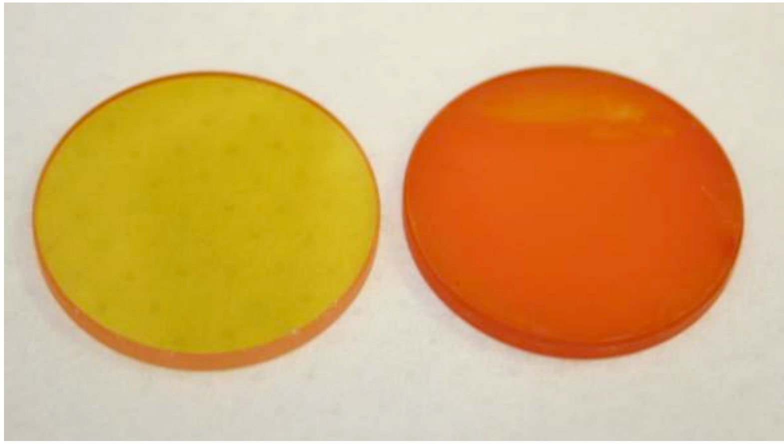
- Broadband anti-reflection performance in the Visible, NIR, SWIR, MWIR and LWIR .
- Anti-reflection performance over 0°-70° of incident angle, for both S and P polarizations
- Ability to be applied to flexible, non-planar substrates, and in well defined areas
- Environmental ruggedness, with nanostructures patterned directly into the substrate
- No chance of delamination, thermal expansion mismatch, or chemical aging
- No flaking, particle formation, or outgassing; Easy cleaning

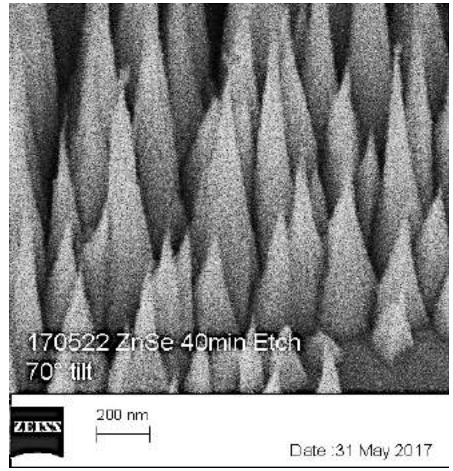
Thermodot ARSS fabrication process

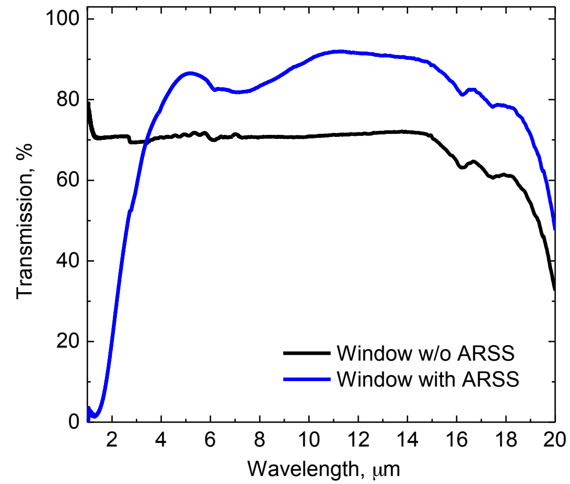


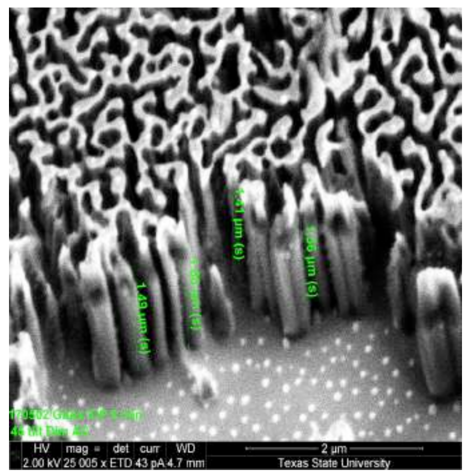


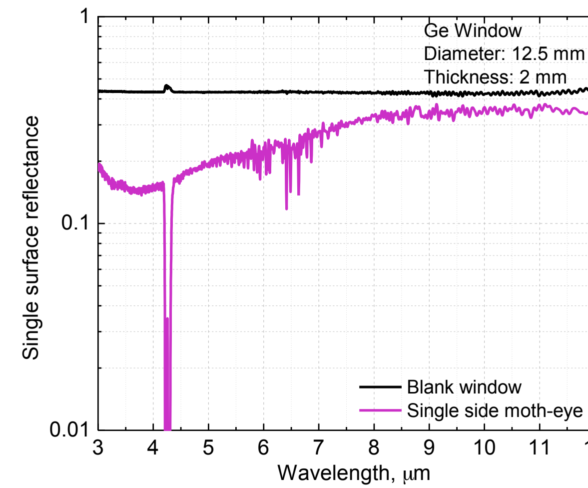
ARSS-enhanced IR windows and substrates











Currently funded by ARMY SBIR Phase 2

Fabrication procedure

(1) Substrate cleaning (dilute piranha, solvent clean)

(2) Buffer layer deposition (SiO_2, 50 – 500 nm thick)

(3)Ag thin film deposition (10–30 nm)

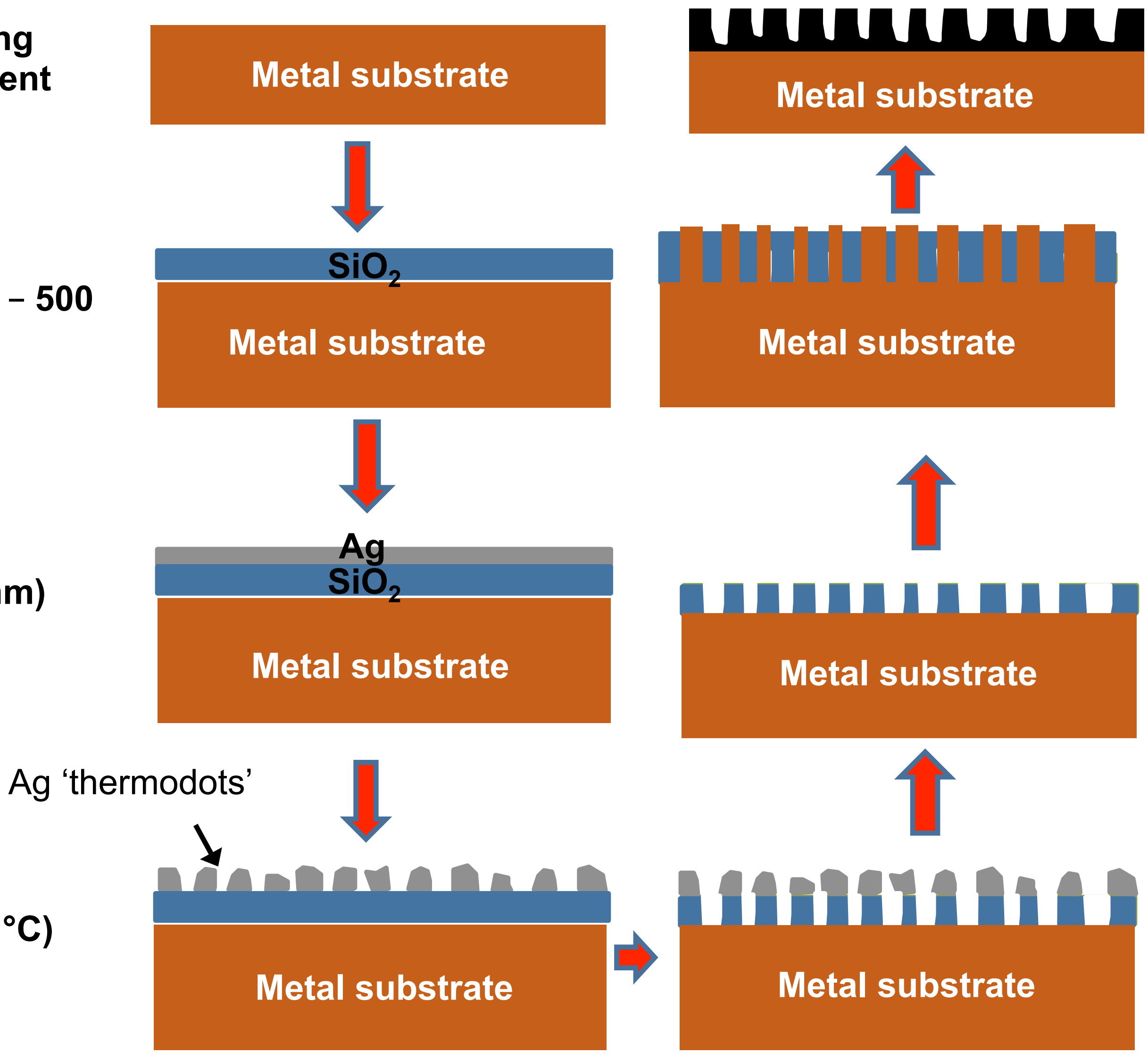
(4) Rapid Thermal Annealing (300–700 °C)

(5) RIE dry etching of SiO_2

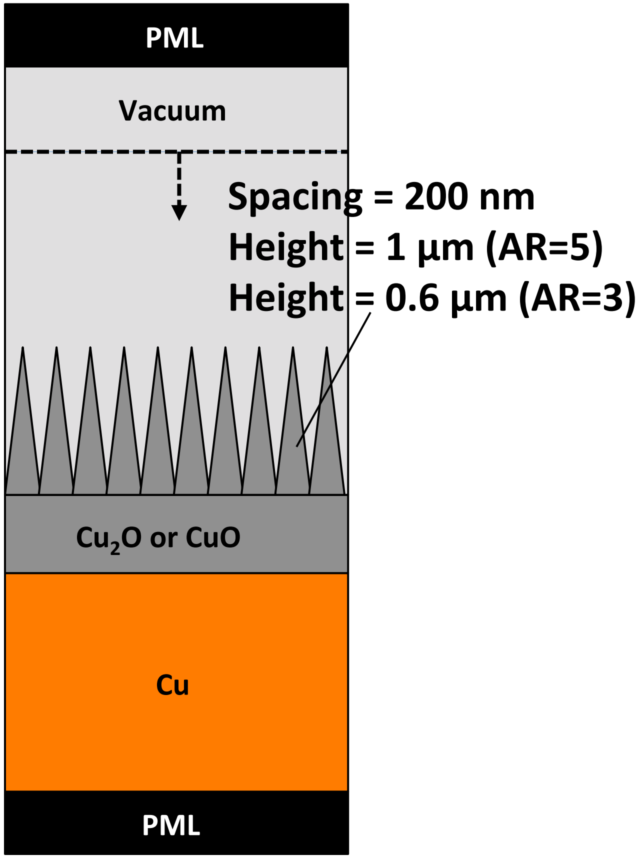
(6) Remove Ag nanoparticle mask

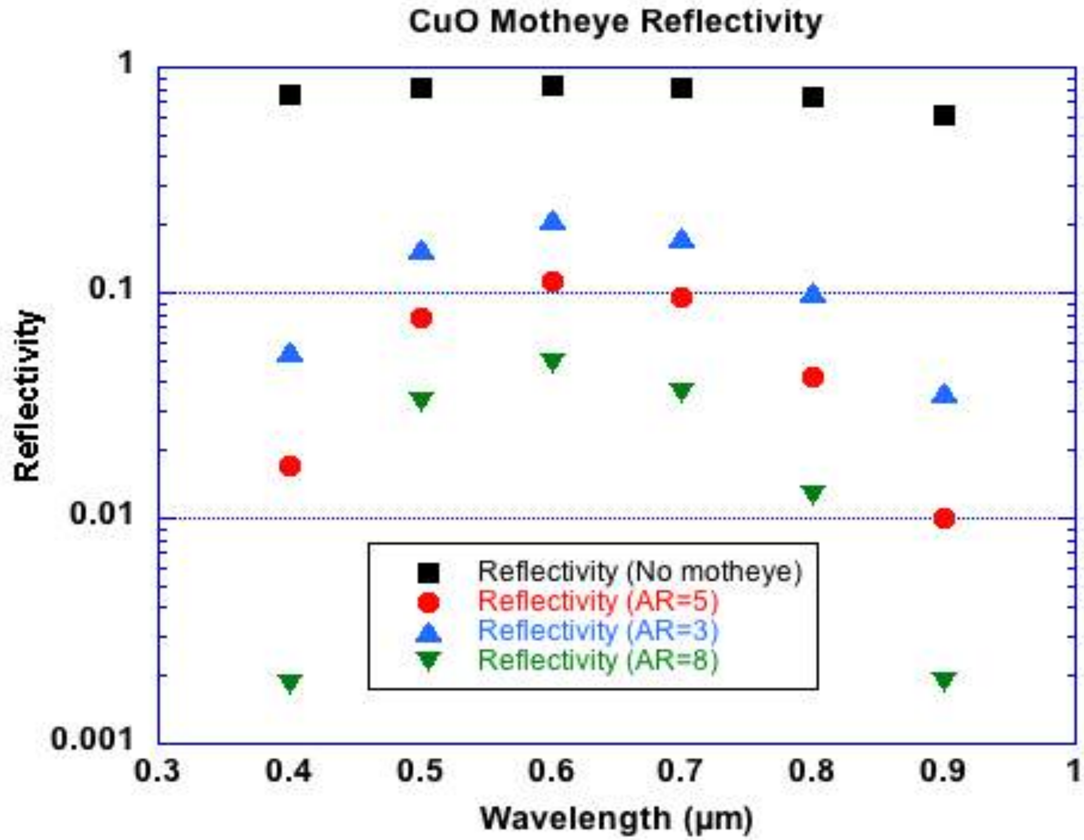
(7) Copper plating

(8) Strip SiO_2 and chemical oxidation



Copper oxide ARSS modeling results



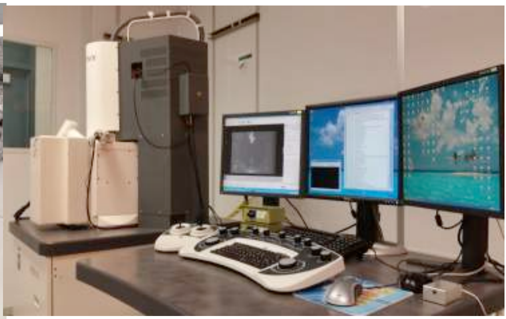


- Copper Oxide optical properties taken from literature
- Periodic structure simulated with varying aspect ratios
- Extract size parameters for optimized reflection suppression at a given wavelength

Fabrication and characterization facilities

Nanohmics

UT Austin - MRC



- Class 100/1000 clean room
- Reactive ion etch systems, plasma deposition systems, thermal and electron beam evaporators, scanning electron microscopy, etc.

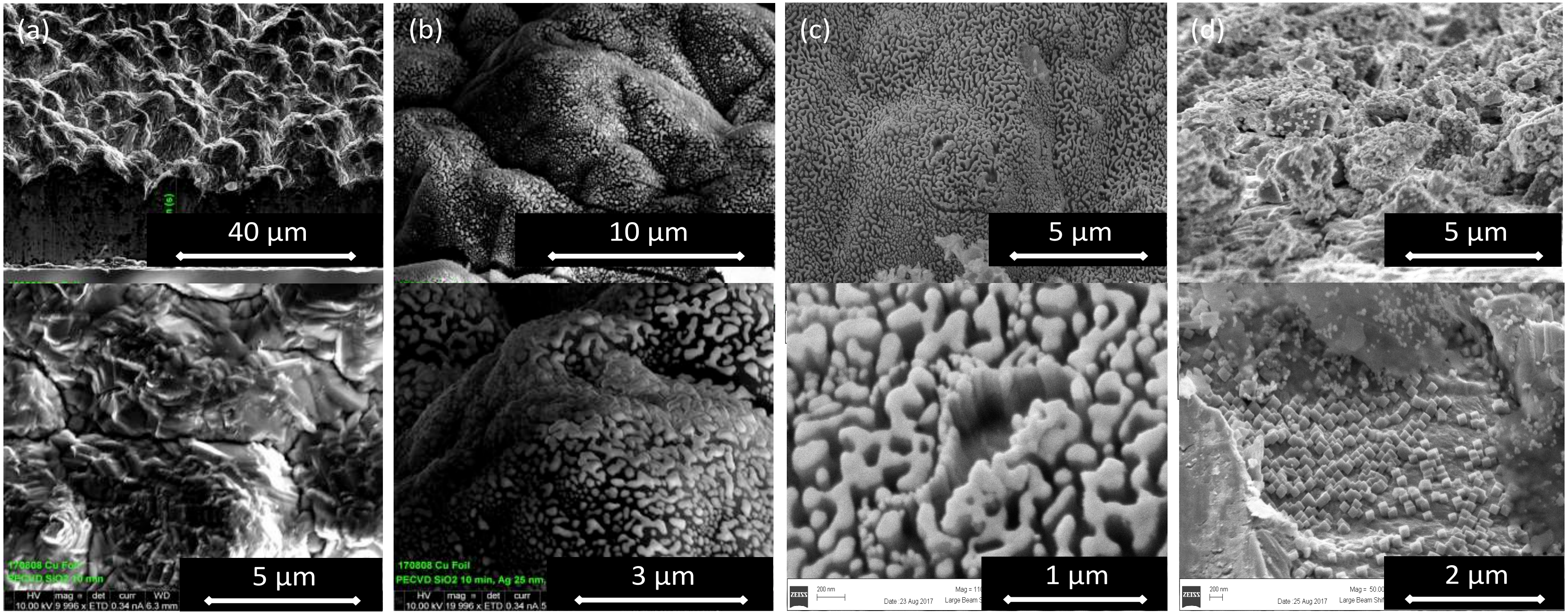
Fabrication on Copper foils and substrates

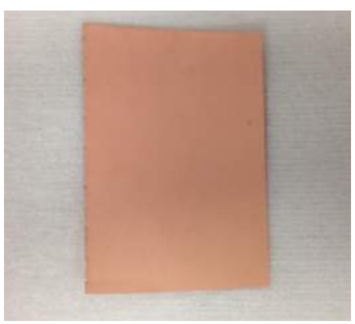
PECVD SiO_2 (500 nm) on Cu foil

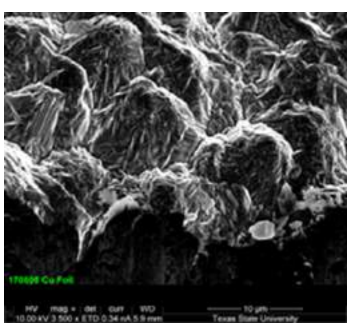
Ag (25 nm) thermodots (500 °C, 120 sec) on SiO_2 on Cu foil

Networked SiO_2 mask on Cu foil

"Networked" electroplated copper on Cu foil







- Successfully fabricated ARSS moth-eyes on Copper foils
- *Copper electroplates completely over the ARSS!*

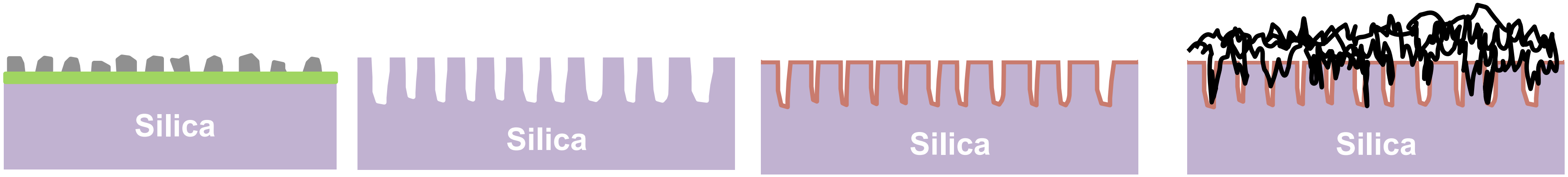
Copper Oxide on thermodot-patterned Silica

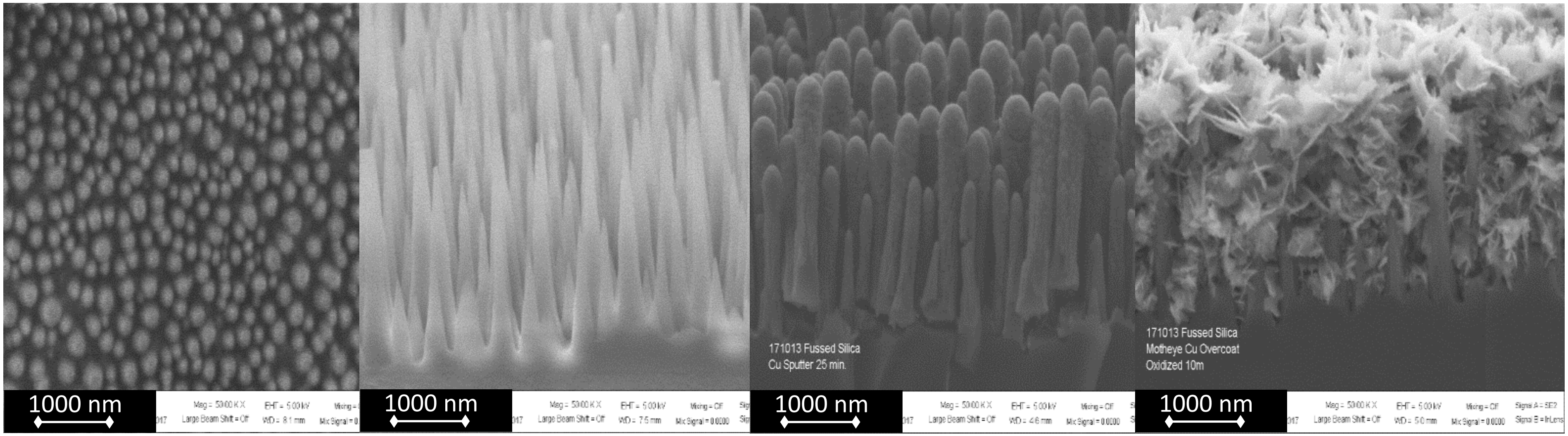
Thermodot
- Ni 10 nm
- RTA 800 °C

RIE Etch
- CHF_3:N_2:Ar
- 80 min - 2 µm

Conformal Coat
- Sputter-deposit 500-nm thick CU

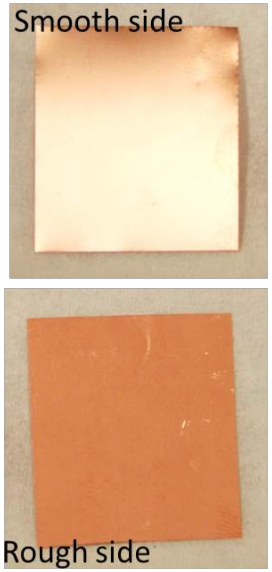
Chemical Oxidation
- NaOH:$K_2S_2O_8$ bath at 70 °C for 10 min



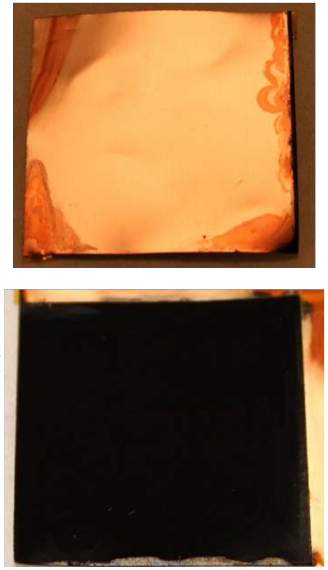


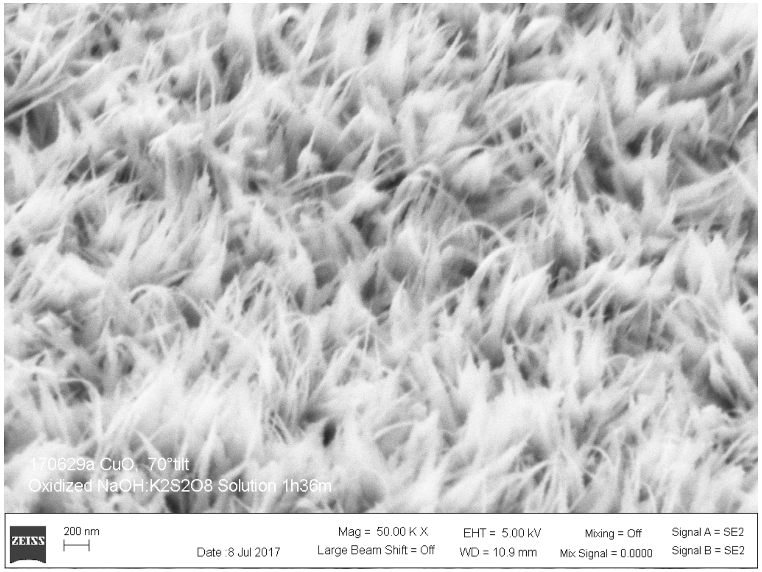
Chemically synthesized copper oxide is forms over the ARSS moth-eye structures and is naturally textured!

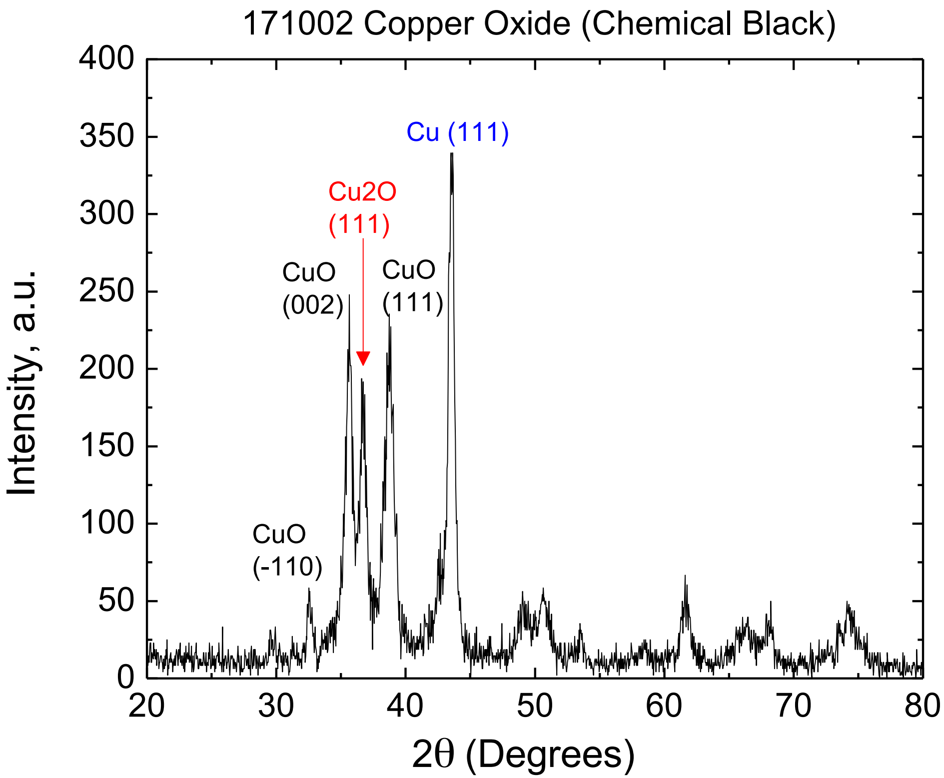
Chemically Black Copper Oxide



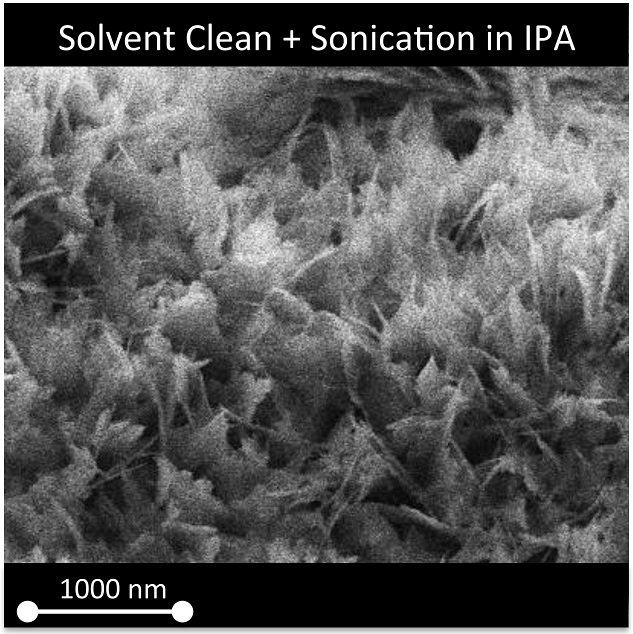
Chemical blackening

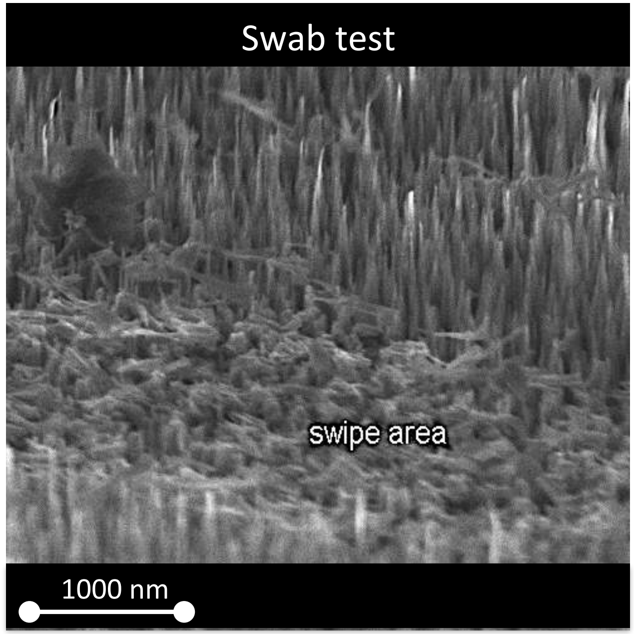


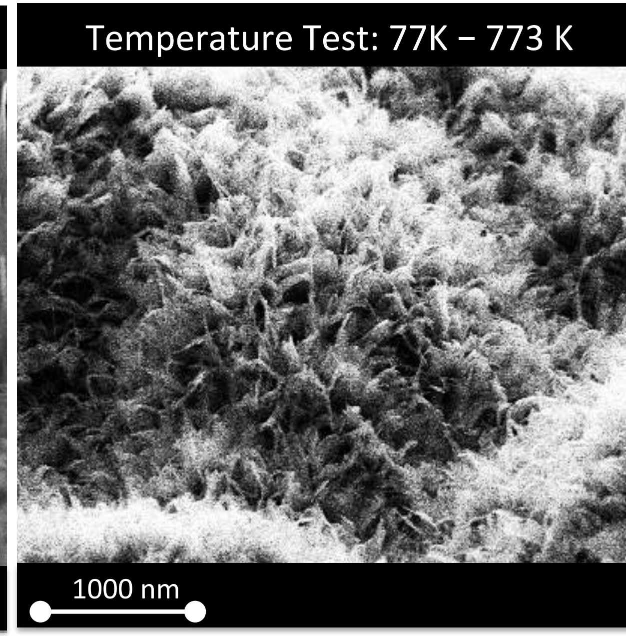




Environmental testing





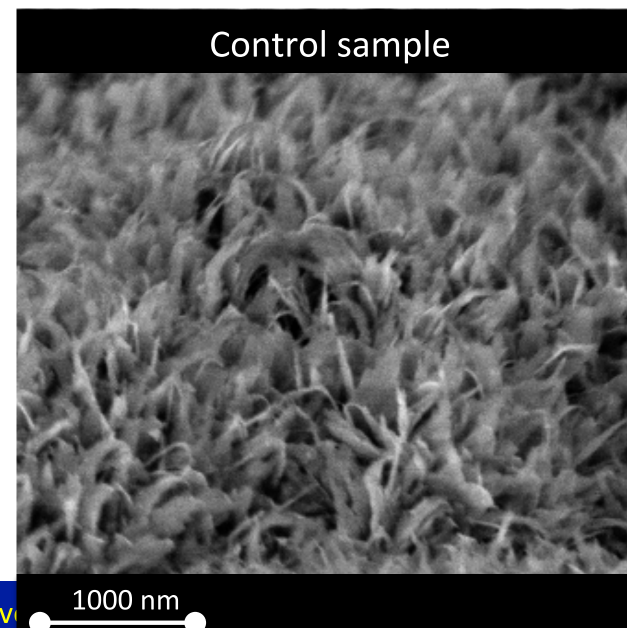


Tolerant against:

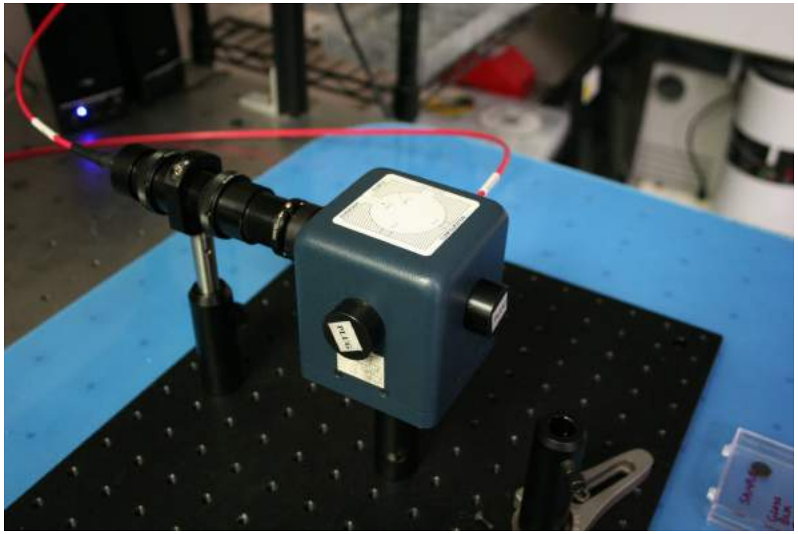
- Standard solvent cleans
- Broad operating temperature range (77 – 773 K)
- Outgassing (10^{-8} Torr)
- Bending and folding (flexible foils)

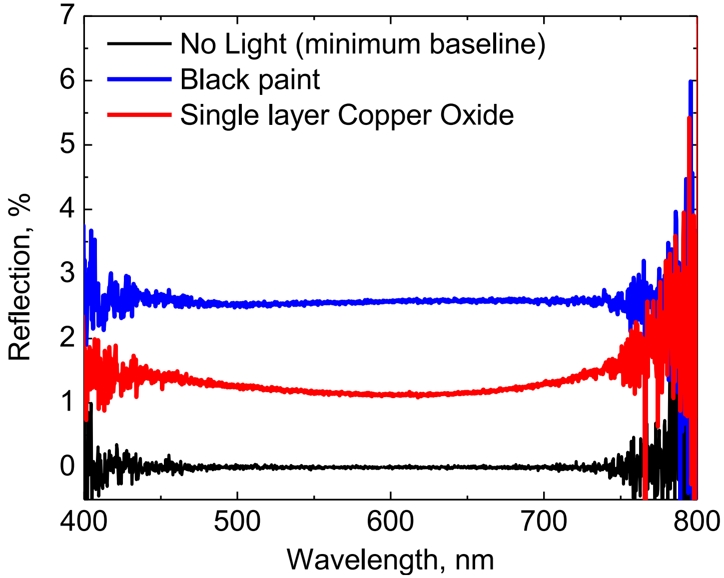
Room for improvement:

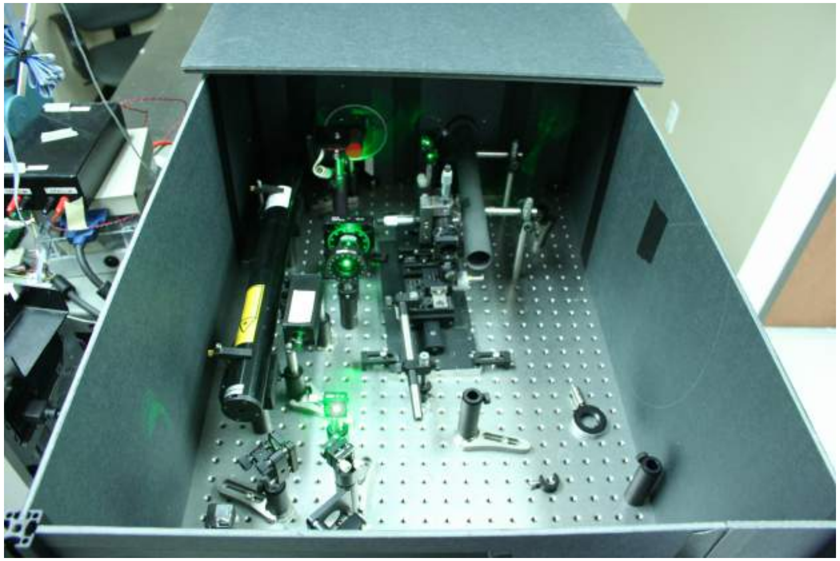
- Wiping, swabbing, or touch

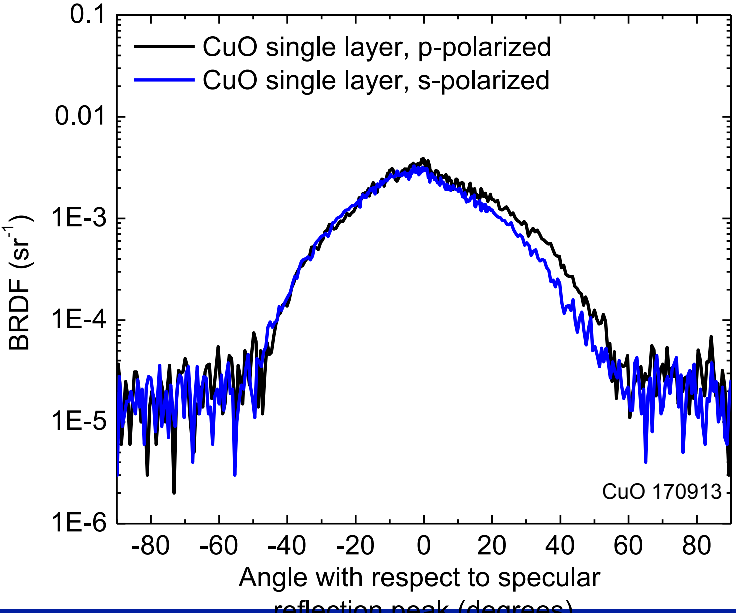


Preliminary reflectivity characterization







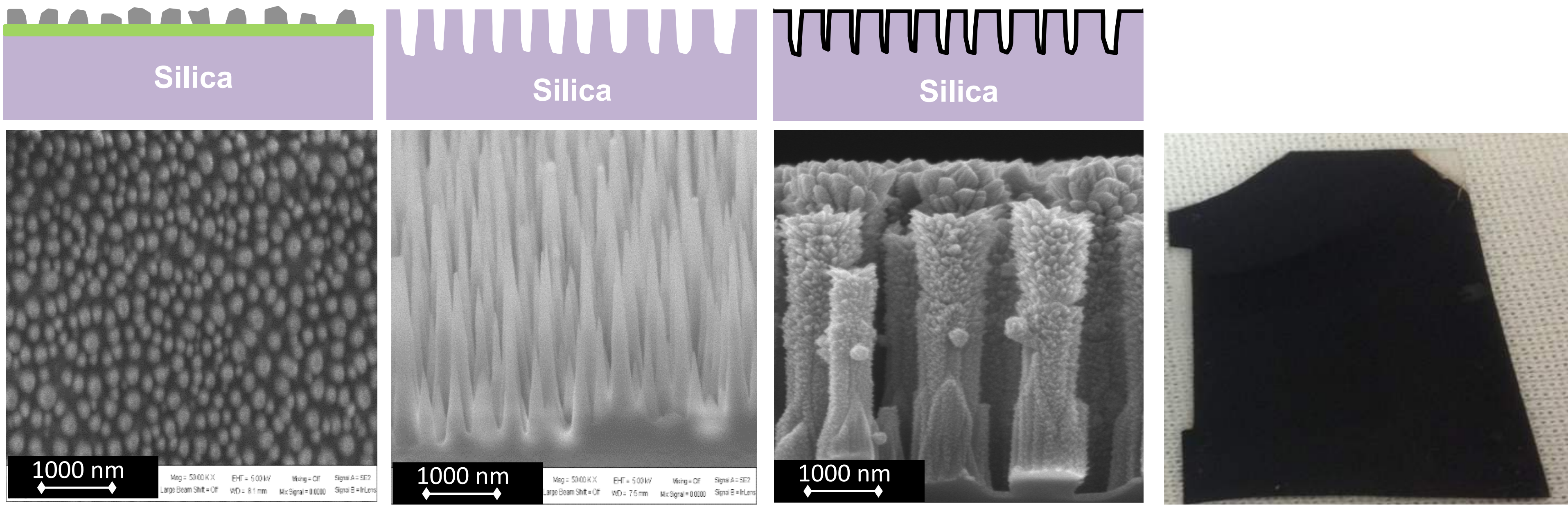


Sputtered Copper Oxide on patterned Silica

Thermodot
- Ni 10 nm
- RTA 800 °C

RIE Etch
- CHF_3:N_2:Ar
- 80 min - 2 µm

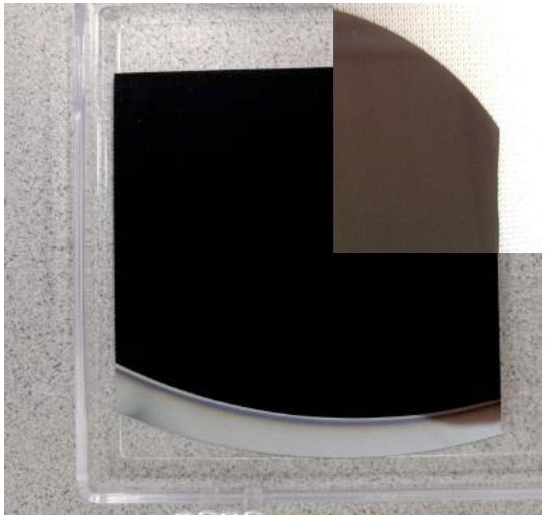
Conformal Coat
- Sputter-deposit 500-nm thick CuO
- Conformal coating without peeling

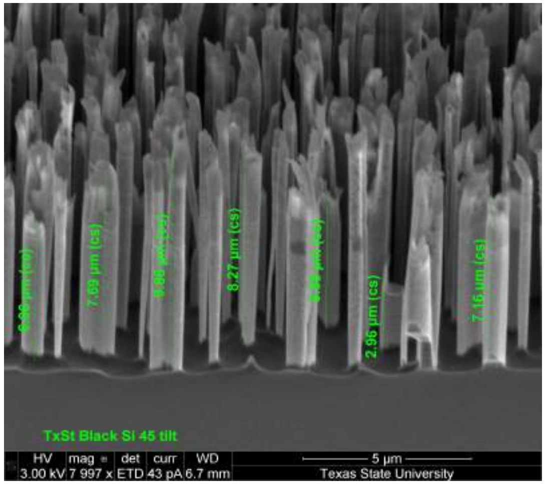


- Form anti-reflective surface structures in a host substrate
- Deposit copper oxide with Argon-assisted magnetron sputtering
- Films have good adhesion and immune to cleaning procedures and processes
- Currently evaluating the spectral performance!

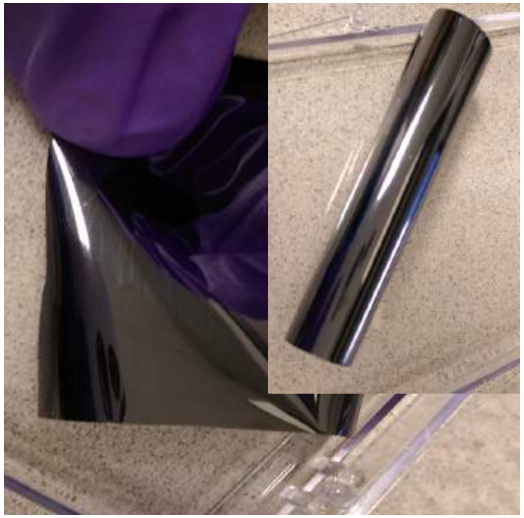
Flexible black silicon

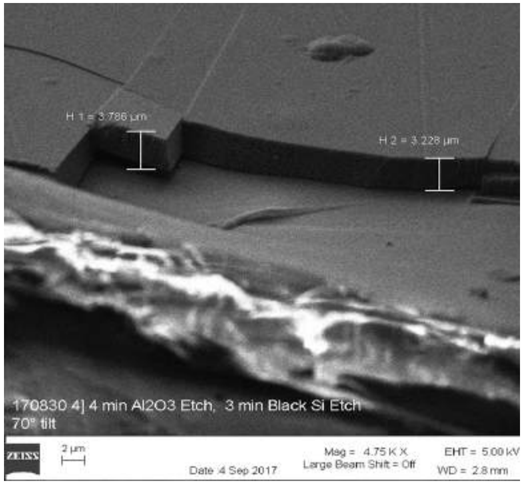
Dry etched Black Silicon on Si wafer



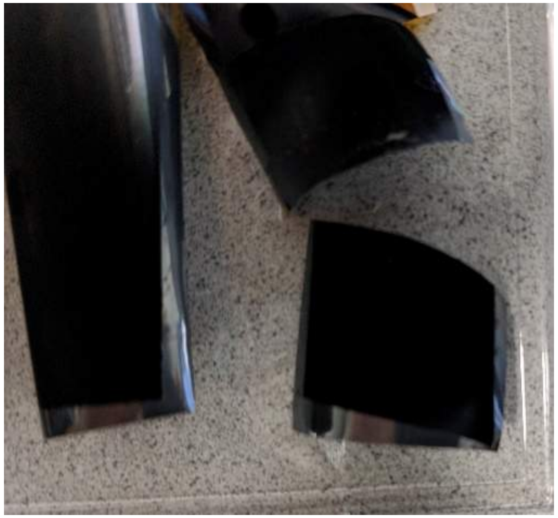


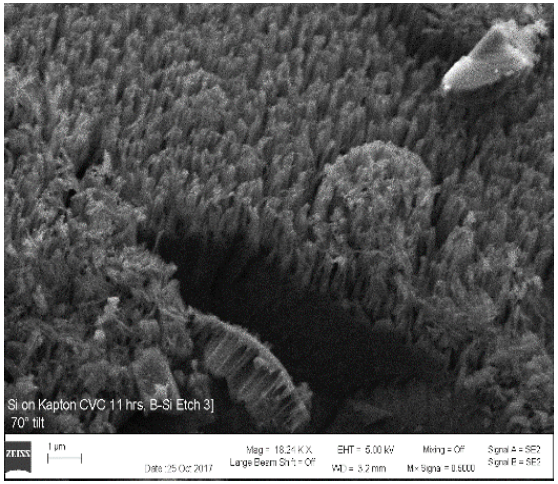
Sputtered Si on Kapton films





Dry etched Black Silicon on Kapton





Summary

- Chemically synthesized CuO on flexible foils and substrates are naturally surface textured.
- Preliminary spectral reflectance ~1% in the visible
- Robust against standard solvent cleaning, heating, cooling and agitation
- Continuing to explore methods of adapting anti-reflective surface structures to CuO
- Currently evaluating sputtered CuO on structures substrates