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!

Advantages of anti-reflective surface structure (moth-eye’s)

- 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

1. Substrate cleaning

2. Buffer layer (AIN, SiO$_2$) deposition

3. Ni thin film deposition

4. Rapid Thermal Annealing

5. ICP-RIE dry etching

6. Remove Ni nanoparticle mask

Nickel film thickness determines particle size

Completely monolithic!
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 (SiO₂, 50 – 500 nm thick)

(3) Ag thin film deposition (10-30 nm)

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

(5) RIE dry etching of SiO₂

(6) Remove Ag nanoparticle mask

(7) Copper plating

(8) Strip SiO₂ 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

- 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
- CHF₃:N₂:Ar
- 80 min - 2 μm

Conformal Coat
- Sputter-deposit 500-nm thick CU

Chemical Oxidation
- NaOH:K₂S₂O₈ 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

Smooth side

Chemical blackening

Rough side

171002 Copper Oxide (Chemical Black)

Intensity, a.u.

2θ (Degrees)

CuO (111)

Cu2O (111)

CuO (002)

CuO (-110)
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

![Experiment Setup](image1.jpg)

**Graph 1:**
- **x-axis:** Wavelength, nm
- **y-axis:** Reflection, %
- **Lines:**
  - Black line: No Light (minimum baseline)
  - Blue line: Black paint
  - Red line: Single layer Copper Oxide

**Graph 2:**
- **x-axis:** Angle with respect to specular reflection peak (degrees)
- **y-axis:** BRDF (sr⁻¹)
- **Lines:**
  - Black line: CuO single layer, p-polarized
  - Blue line: CuO single layer, s-polarized

_Nanohmics Inc._

_Proximity Glare Suppression – Mirror Technology Workshop, November 15, 2017_
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